INTERNATIONAL LIBRARY OF TECHNOLOGY

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

PRINCIPLES OF TELEPHONY
PROPERTIES OF TELEPHONE CIRCUITS
TELEPHONE RECEIVERS
TELEPHONE TRANSMITTERS
TELEPHONE APPARATUS
MAGNETO-GENERATORS AND BELLS
CIRCUITS OF TELEPHONE INSTRUMENTS
TELEPHONE INSTRUMENTS
INSTALLATION OF TELEPHONES
LINE DISTURBANCES AND TRANSPOSITIONS
LONG-DISTANCE TELEPHONY
MAGNETO-SWITCHBOARDS
LARGE MAGNETO-SWITCHBOARDS
TELEPHONE-SWITCHBOARD APPARATUS

SCRANTON:
INTERNATIONAL TEXTBOOK COMPANY
25B

PRINTED IN THE UNITED STATES.

20197

25B

PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one select the proper formula, method, or process and in teaching him how and when it should be used.

This volume gives a clear explanation of the principles of telephony and the properties of telephone circuits, including enough on the subject of variable and alternating currents to enable one to understand the operation of any telephone device or system. The latest types of receivers, transmitters, bells, magneto-generators, hook switches, and complete telephone instruments are then described. The wiring of buildings and the installation of telephones is thoroughly treated, while disturbances to line circuits and their elimination, the location and construction of transpositions, and both small and large magneto-switchboards are fully explained. Long distance telephony and Professor Pupin's method of applying loading coils to line circuits are logically discussed. American telephone practice is acknowledged to be in advance of that in any country, consequently, a thorough discussion of American practice and of the fundamental principles on which it is based, such as is here contained, makes the treatise by far the most complete on the subject that has yet been published.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

INTERNATIONAL TEXTBOOK COMPANY

128

CONTENTS

PRINCIPLES OF TELEPHONY

ACOUSTICS

SOUND

1. Acoustics is that branch of physics which treats of the phenomena and laws of *sound* and *sound waves.*

There are two distinct definitions of **sound**: First, sound is the sensation that is perceived when the nerves of hearing are properly excited; and, second, sound is a physical disturbance capable of producing on the auditory nerves the sensation of hearing.

According to the first definition, therefore, sound is the sensation itself, while according to the second, it is the stimulus or cause of the sensation. The word sound will be used in this treatise according to both these definitions, proper care being taken, however, to prevent any likelihood of confusion between the two.

WAVE MOTION

2. The physical disturbance capable of exciting the auditory nerves is a **wave motion** passing from some vibrating body through some material medium, which is usually air, though it may be any gas, solid, or liquid. It is well established that all action between points or bodies separated by space is due to vibrations of the medium filling this space, no matter what that medium may be. In the phenomena of light, heat, or electricity, the medium is the ether; while in the case of sound, some more tangible medium, such as a gas, liquid, or solid, is needed.

SOUND WAVES

3. Vibrating Diaphragm.—In order to understand more clearly the nature of the propagation of **sound waves** in any substance, those set up by a vibrating diaphragm, such as shown in Fig. 1, will be considered. This diaphragm is

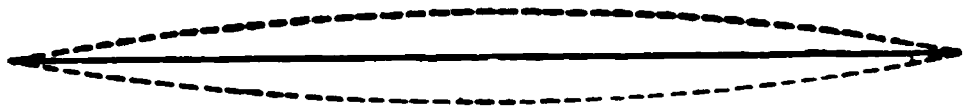


FIG 1

supposed to be of some thin elastic substance, such as sheet iron, and to be firmly supported at its edges. It is supposed, moreover, that it is maintained by some means in a constant rapid vibration to and fro between the limits indicated by the curved dotted lines.

As it moves to the right, there is produced a condensation of the atmosphere immediately in front of it at *C* and a rarefaction immediately in the rear of it at *R*, as shown in Fig. 2. The condensation at *C* is communicated to the particles of air at the right of *C*, and by them to the particles of air at their right, and so on. A wave of condensation therefore travels to the right through the air, gradually diminishing in intensity until it is finally lost. When it moves back to the left, the plate causes a rarefaction at *C* and the particles of air from *A* rush into it, thus causing a rarefaction at *A*, which in turn is filled by particles in the space at its right. Thus, a wave of rarefaction follows the wave of condensation, and this in turn is followed by another wave of condensation, and so on as long as the plate continues to vibrate. A similar set of waves, but in reverse order—a wave of condensation following a wave of rarefaction—is also sent out in the opposite direction by the other side of the plate.

4. Movements of Particles in Wave.—Consideration will show that while the wave travels outwards from the diaphragm, the particles of air through which the wave is propagated move only to and fro in a comparatively limited path. A similar action takes place when a pebble is dropped into a pond of still water. Waves are set up that proceed

in the form of circles, of which the point where the pebble entered the water is the center. The wave undoubtedly travels over the surface of the water; but by observing small chips floating on the water, it will be seen that they move only up and down when acted on by the wave. So it is with the particles of air or of any other medium through which

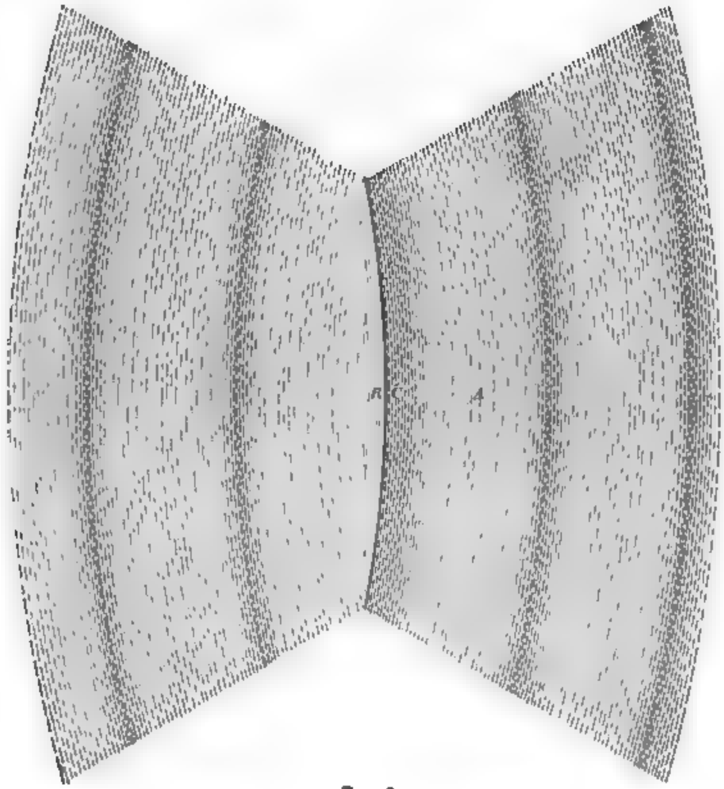


FIG. 2

wave motion is being transmitted. In the case of sound waves, the to-and-fro motion of the particles of air is in the direction of the line of propagation of the wave itself, while in the case of ripples on the water, the to-and-fro motion of the various particles of water is at right angles to the line of propagation of the wave.

5. Graphical Representation.—A vibrating body, such as a tuning fork, will send out waves, in the air, that follow each other in regular succession. These waves may be represented, graphically, as in Fig. 3. Consider the wave to be moving in the direction of the line *A B*, then the displacement of a particle of air at any point in the wave will be

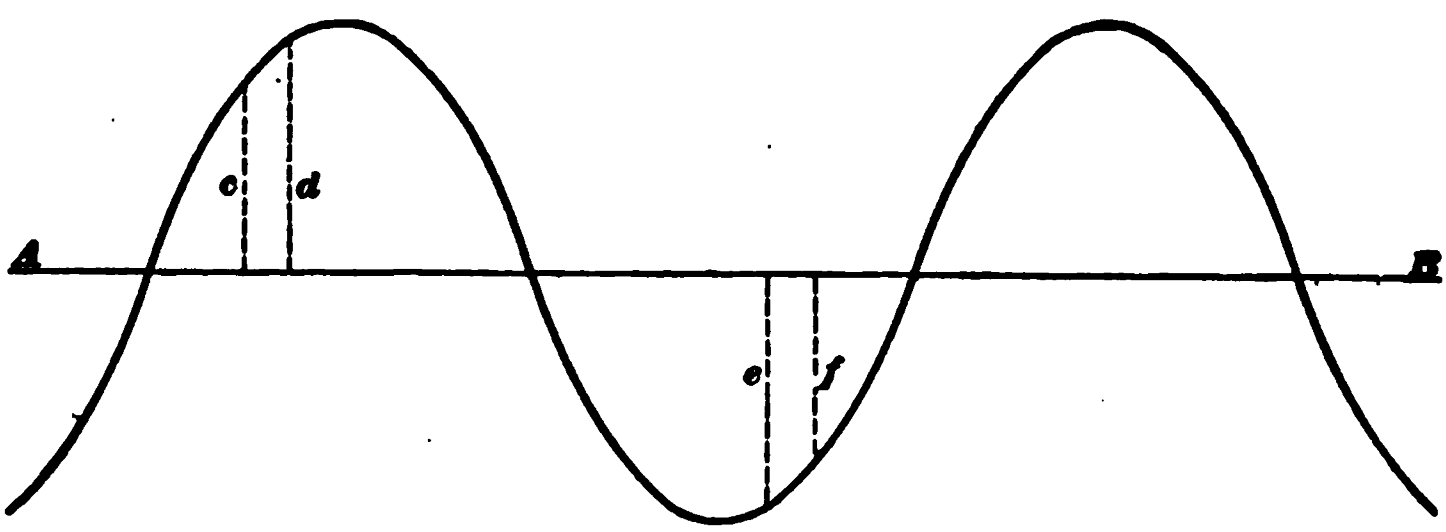


FIG. 3

represented by the length of the dotted lines *c*, *d*, *e*, *f*, etc.; i. e., the particle has moved that far from its normal position of rest.

In order that the curve may be readily comprehended, the amount of the motion of the particles, or their displacement from their position when at rest, is represented as being at right angles to the line *A B*, although the particles are really vibrating to and fro in the direction of this line.

THE EAR

6. If these waves originate in or are communicated to the medium in which the ear is situated, then at each recurring condensation the elastic membrane, called the **tympanum**, or **drum**, of the ear will be pressed inwards, and at each recurring rarefaction will be drawn outwards. These vibrations will be transmitted by means of a chain of bones, termed the **hammer**, **anvil**, and **stirrup**, to the membranous wall that closes an internal cavity, called the **vestibule**, through it and some canal-like passages filled with a liquid and containing ramifications of the auricular nerve, which the vibrations finally reach and excite. This nerve

ends in minute rods or fibers, each of which seems to vibrate at a definite frequency, and each one is excited only by a wave having the same period of vibration.

The greater the degree of condensation and rarefaction of the medium in a given time, the greater will be the motion of the drum of the ear, and, consequently, of the mechanism of the ear that acts on the nerves. Hence, it follows that the function of the human ear is the mechanical transmission to the auricular nerve of each expansion and contraction that occurs in the surrounding medium, while the function of the nerve is to convey to the brain the sensations thus produced. From the above, one can understand why it is possible to make some persons who are deaf on account of an unnatural condition of some part of the ear mechanism hear by the use of apparatus that collects and transmits sound vibrations through the teeth and bones in the head to the auricular nerve. The nerve itself must, of course, in order to accomplish this, be in a natural state, free from disease.

SIMPLE HARMONIC MOTION

7. Such a curve as that shown in Fig. 3 represents what is termed *simple harmonic motion*, which is a most important form of vibration, not only in acoustics, but in all other branches of physics relating to wave motion. If a pin head p', Fig. 4, on a disk D revolving at a uniform speed is allowed to cast a shadow perpendicularly on a plane at right angles to the disk, the movement of this shadow will be a simple harmonic vibration. The movement, of course, will be in a straight line, as shown at pp. Starting at one end of the path, the shadow will move slowly at first, but with increasing velocity,

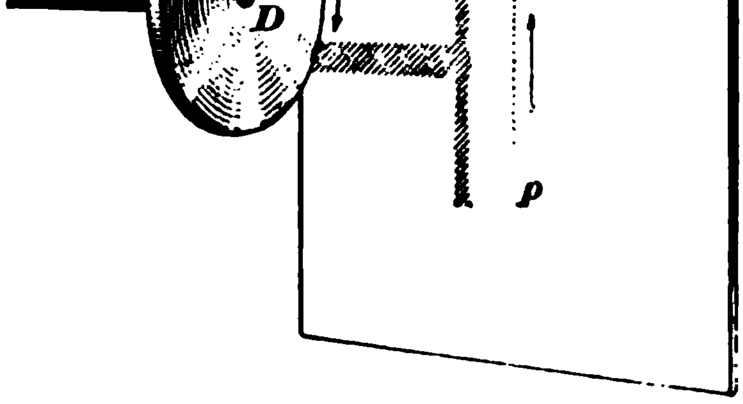


FIG. 4

until the middle point of its path is reached. Here the velocity will be a maximum, and after passing this point, it will decrease more and more rapidly until it comes to rest momentarily at the other end of the path. The direction of motion will then be reversed, and the shadow will again attain its maximum velocity in the other direction at the center point in its path, and will again come to rest momentarily at the starting point.

8. Simple harmonic motion may be defined as the movement of the projection on a fixed straight line of a point moving uniformly in a circular path. This definition will perhaps be made clearer by considering Fig. 5. Let p' be a point moving with a uniform velocity in a circular path

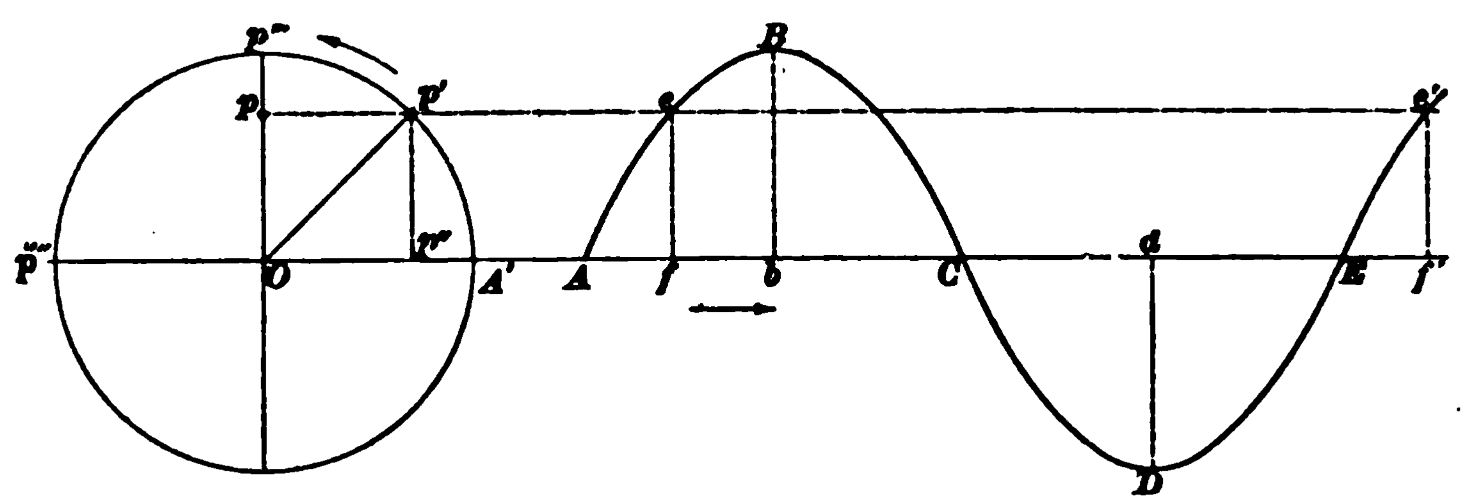


FIG. 5

of which the center is O, the direction of motion being as indicated by the curved arrow. The projection p of the point on the vertical diameter of this circle will, it is evident, move from one end of this diameter to the other in exactly the same manner as did the shadow of the pin head in Fig. 4. If, while the projected point p in Fig. 5 is moving along the vertical diameter with harmonic motion, it should be caused to trace its course on a sheet of paper by drawing the paper with a uniform motion from right to left under the point, the path on the paper would be as indicated by the curved line $ABCDE$. The beginning A of the curve corresponds to a time when the point p' was at the point A' on the circumference. As the movement progresses, the curve will gradually rise to a maximum height at B, which is reached when the point p' has been rotated from its original

position A' through 90° of the circle to its highest position p'''. The curve will then descend and reach the zero line at C, when the point p' has been rotated through an angle of 180° to p''''. The next half of the revolution of the point p' will cause its projected point p to trace a curve below the line exactly similar to that traced by the first half above the line.

9. Amplitude.—The amplitude of vibration is the maximum displacement of the point p from its center position O. Thus, in Fig. 4 the amplitude would be represented by one-half the length of the line $p\ p$, and in Fig. 5 by the radius of the circle.

10. Cycle.—A complete vibration to and fro of the point p, corresponding to a rotation of the point p' through 360° is termed a **cycle**. A complete cycle would therefore be represented by the part $ABCDE$ of the curve, Ee' being part of the next cycle. It is seen that in its vibration the point p, Fig. 5, has completed one full cycle and has started on the next, being at the time shown at the point e' on the curve. The distance AE is the length of one complete wave, and is called the **wave length**.

It is evident that simple harmonic motion, although taking place in a straight line, is very closely allied to circular motion, and it is therefore customary to deal with it by means of angular measure. Thus, a complete cycle would be represented by 360°, or by $2\ \pi\ r$, where r is the radius of the circle, or the amplitude of vibration.

11. Phase.—The portion of a cycle through which a vibrating point has passed at a given time is called the **phase** of the vibration, and is usually expressed in angular measure. Thus, the point B on the curve in Fig. 5 represents a phase of 90°; the point C, a phase of 180°; the point D, 270°; and the point E, 360°, or a complete cycle.

12. Frequency.—The number of complete cycles occurring in 1 second of time is called the **frequency** of the vibration. The term frequency is often misused by representing it as the number of half vibrations that occur in a second.

13. Period.—The **period** of a vibration is the time that elapses during one complete cycle; thus, if T represents the period and n the frequency, it is evident that $T = \frac{1}{n}$. It is the time required for the wave to move from A to E in Fig. 5. The horizontal distance measured along the line $A\,E$ may be taken as a measure of the time elapsing during the passage of the point p from any point on the diameter of the circle to any other point, or it may be taken as a measure of the angle through which the point p' has rotated from its original position A'. Thus, if it takes the point p just 4 seconds to pass from the center point O through a complete cycle back to that point, it is evident that the distance $A\,E$ will represent the time of one complete cycle, that is, 4 seconds. It may also represent the angular rotation of the point p', and in circular measure will be 360°, or $2\pi r$. In a like manner, the distance $A\,b$ will represent a time of 1 second, since it is one-fourth of $A\,E$, or an angular rotation of 90°; the distance $A\,C$, a time of 2 seconds, or an angular rotation of 180°; and the distance $A\,d$, a time of 3 seconds, or an angular rotation of 270°.

THE CURVE OF SINES

14. The curve shown in Fig. 5, which is used to represent simple harmonic motion, may also represent all the values of the sine of an angle, while the angle is uniformly increasing from 0°, and is therefore termed the **curve of sines**, or the **sine curve**.

It has been shown that the distances from the point A in a horizontal direction may be considered as measures of the angle through which the point p' and the line $O\,p'$ has rotated. In a similar manner, it may be shown that the ordinate of the curve at any point, that is, the perpendicular distance from the curve to the base line, is a measure of the sine of the angle represented by the horizontal distance of that point from the reference point A, for $\sin A'\,O\,p' = \frac{p'\,p''}{O\,p'}$,

or $p'p'' = Op' \sin A'Op' = r \sin A'Op'$, where r is the radius of the circle, or the amplitude of vibration.

Now, $p'p'' = Op$, and as any ordinate ef at any point on the curve is always equal to the distance Op for the corresponding angle, it follows that any ordinate on the curve will be $ef = r \sin A'Op'$, where $A'Op'$ is the angle corresponding to the position taken on the curve.

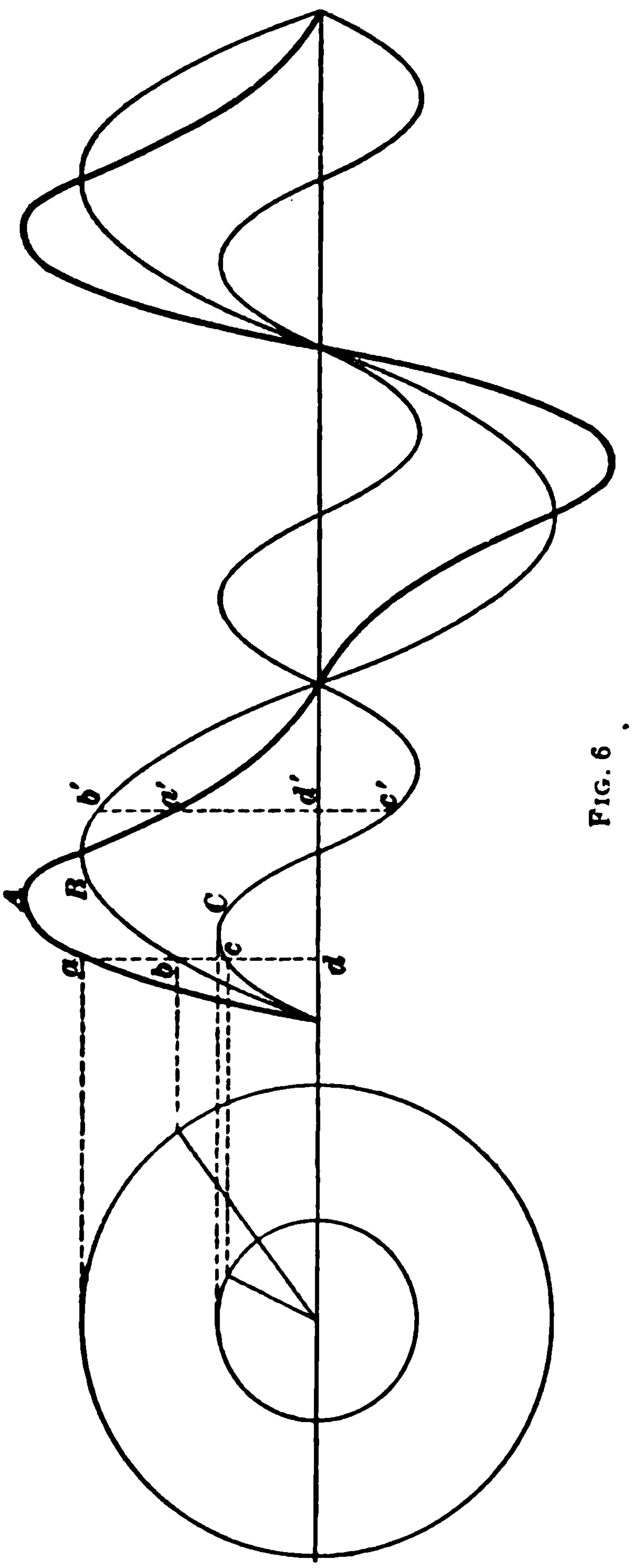


Fig. 6

COMPLEX WAVE MOTION

15. Even though the vibrations of a point may be periodic, that is, regularly recurring, they may not follow such a simple law as that of simple harmonic motion. A vibration that is not harmonic is represented by the curve A, Fig. 6, and this wave may be considered as the resultant of two sine waves B and C, of which C has twice as great a frequency as B. It is readily seen from the curves that C makes just twice as many complete vibrations in a given time as B. The curve A is obtained by adding together the ordinates of the curves B and C; thus, the ordinate ad of the point a on the curve A is the sum of the ordinate cd of the curve C and the ordinate bd of the curve B. When the curves B and C are on the opposite sides of the zero

line, the difference of the two ordinates is taken. Thus, the point a' on the curve A is determined by subtracting the ordinate $c'd'$ of curve C from the ordinate $b'd'$ of the curve B. The curve A is called the resultant of the curves B and C.

16. Fourier's Theorem.—This theorem states that any complex periodic vibration may be considered as the resultant of a number of simple vibrations, of which the frequencies are 1, 2, 3, 4, etc. times the frequency of the complex vibration. This is illustrated in Fig. 6, where the curve A, representing a compound vibration is composed of two other curves representing simple vibrations, one of which has a frequency the same as that of the compound vibration, and the other of which has a frequency equal to twice that of the compound vibration.

THE LIMITS OF AUDIBILITY

17. All vibrations that set up waves in the manner already mentioned are not capable of producing the sensation of sound.

A uniform series of vibrations, a definite number of which are produced in a given time, and which are within limits capable of exciting the auricular nerves, is called a **tone.** Thus, a simple musical tone results from a continuous, rapid, and uniformly recurring series of vibrations, provided that the number of complete vibrations per second falls within certain limits.

If, for example, the vibrations number less than 32 per second, a series of successive noises are heard, while, if their number is greater than 40,000 per second, the ear is not capable of appreciating the sound. Of course, different people have very different powers of hearing. The number of vibrations of a musical tone is somewhere between 35,000 and 32 per second, and the number of vibrations produced by the human voice when talking is between 61 and 1,305 per second. In ordinary conversation, the average frequency is about 300 per second.

CHARACTERISTICS OF SOUND

18. All sounds have **three characteristics**, variations in which enable us to distinguish between the different sounds we hear. They are termed *loudness*, *pitch*, and *timbre*.

19. Loudness.—Loudness is that characteristic of sound which depends on the amplitude of the sound wave. It depends on the amount of energy in the vibrations producing the sound. As an illustration, the striking of a certain key on a piano may be made to produce a loud or a soft sound, according to the degree of force with which the key is struck. If considerable energy is used in striking the key, the corresponding string is made to vibrate with great amplitude, and therefore to give forth a sound of great loudness. The pitch and timbre are the same, whether the key is struck forcibly or lightly. Loudness is the intensity of sound.

20. Pitch.—Pitch depends entirely on the number of vibrations per second, that is, on the frequency. A low rate of vibration produces what is called a low tone and a high rate a high or shrill tone. The difference between the sounds emitted by long and short strings of the same material and of equal size and tension is one of pitch. This is well illustrated in the violin, where the same string may be made to give forth a low or a high tone by merely varying the effective length of the string by pressing the finger against it at different points. Such a vibration as is illustrated by curve B, Fig. 6, will produce a sound of a certain pitch, while the wave motion represented by curve C in the same figure will produce a tone of twice the pitch, because its frequency or rate of vibration is twice as great as that of the wave B. The fact that the frequency of the wave represented by C is just double that of the wave represented by B will render the tone set up by the former the octave of the latter.

21. Timbre.—Timbre is the quality of sound, and depends only on the form of the sound wave. A pure tone is one produced by a simple vibration, such as is represented in Fig. 3. Such a tone has a very different sound from one

produced by a more complex set of vibrations, as, for instance, those represented by curve *A*, Fig. 6. This curve, as we have seen, is produced by a combination of two simple wave motions, one represented by *B* and the other by *C*. The waves of ordinary musical tones are rather more complex than that shown by *A*, and are usually composed of one simple vibration having the same frequency as that of the complex tone when considered as a whole, and also many other vibrations having frequencies of 2, 3, 4, etc. times the frequency of the first vibration. The wave having the lowest rate of vibration is termed the *fundamental wave* of a composite sound, and those waves of higher rates of vibration are called *overtones*. These latter are due to the fact that the body producing the sound vibrates not only as a whole, but in its various parts, the vibration of the parts of course being of a higher frequency than those of the whole. The timbre or quality of a sound depends not on the amplitude of vibration as does the loudness, nor on the rate of vibration as does the pitch, but on the number of overtones superimposed on the fundamental tone and also on the relative intensities of the overtones to each other and to that of the fundamental. The quality of a tone may therefore be said to depend on the form of the resultant wave.

22. Phase Relation and Wave Form.—To illustrate the effect that the phase relations of the various components of a complex sound may have on the timbre or quality, reference is made to Fig. 7. In this are shown three complex waves *A*, *A′*, and *A″*, each of which is composed of two simple waves *B*, *C*, as in Fig. 6. The component waves *B*, *B*, *B* are in each case alike in amplitude and frequency, as are also the component waves *C*, *C*, *C*. The frequency of waves *C* is, however, twice that of waves *B*. Although having the same components, the form of the resultant wave is entirely different in each of the three cases, this difference being due to the fact that the two component curves differ from each other as to their phase relations in each case. Thus, in curve *A*, the component curve *C*

always passes through the zero line at the same instant as does the component curve *B*. In the curve *A'*, the curve *C* is shifted about 30° (in relation to curve *B*) to the left of the position that it occupied in curve *A*; i. e., one-sixth of

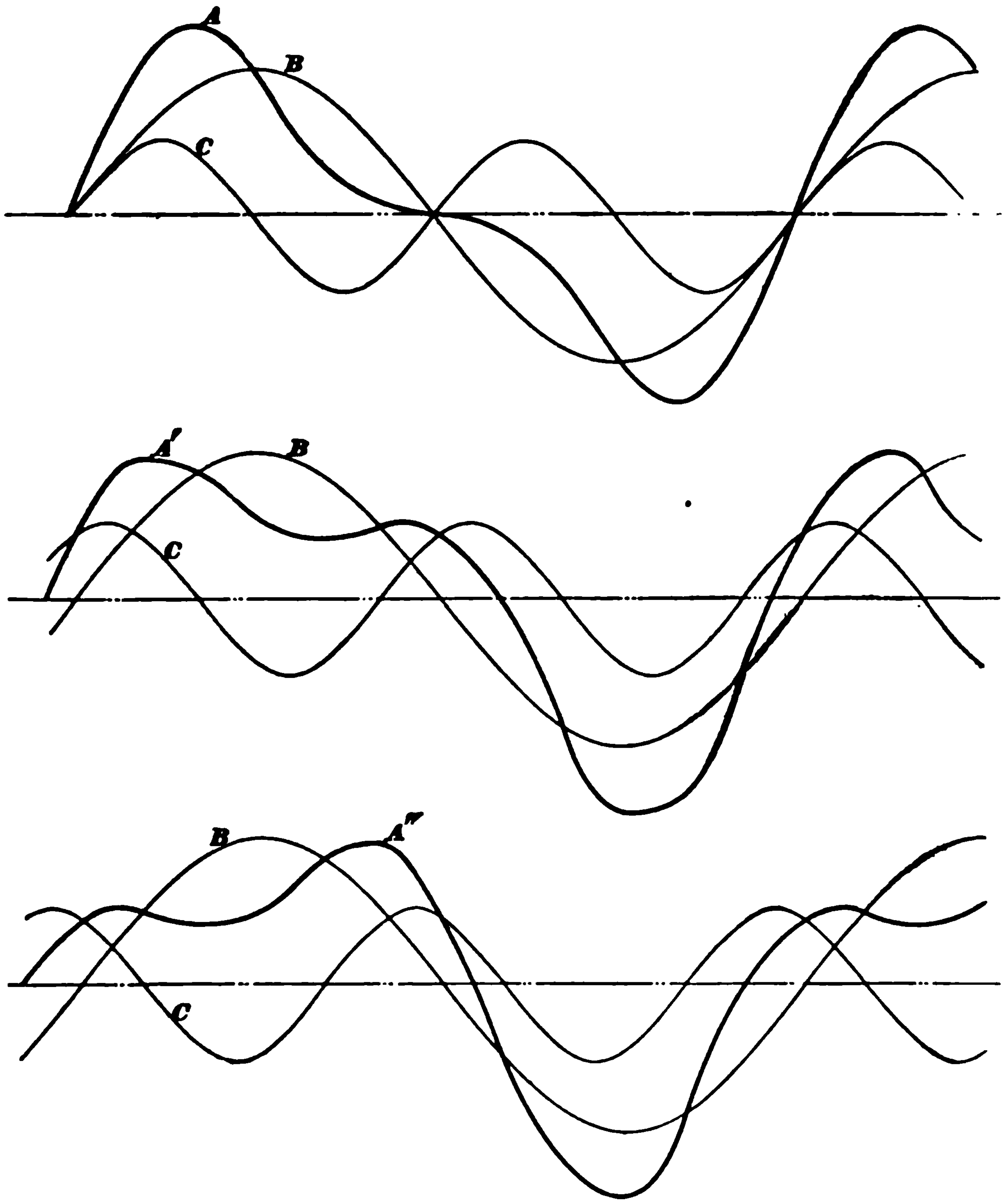


FIG. 7

its own wave length; and in curve *A''*, the curve *C* is again shifted to the left by about an equal amount. The sounds produced by the three wave forms *A*, *A'*, and *A''* will differ not much as to loudness, for their amplitudes are about the same; not as to pitch, for their frequencies

are the same; but considerably as to timbre, because the wave forms are different. The changes in the form of a resultant wave, brought about by shifting the phases of its component parts with respect to each other, is much more apparent where a larger number of components than two is considered. As a familiar illustration of differences in timbre, the same note on the flute, the violin, and the clarinet may have identically the same loudness and also the same pitch, yet the tones will be very different. The note sounded on the violin differs from the same note on the flute, because, although the fundamental of both may be the same in pitch and loudness, the overtones, or, as they are sometimes called, the harmonics, differ both in number and relative intensities. What is recognized by the ear as the pitch of such sounds is, in reality, the pitch of only one of these tones, that is, the fundamental, because it is usually the most prominent. This difference in the above two sounds is due to timbre alone.

ARTICULATE SPEECH

23. The successive vibrations set up by the vocal organs, forming distinguishable and intelligible sounds, are called **articulate speech.** These vibrations, which are roughly represented in Fig. 8, are the most complex in the whole realm of sound—so complex, in fact, as to defy mathematical analysis; but it is certain that their variations in

FIG. 8

loudness, pitch, and timbre depend on the facts already outlined. By means of these variations, we are not only enabled to understand the words spoken by others, with all their various shades of intonation and corresponding shades of meaning, but we are enabled to distinguish between the voices of the many people with whom we are acquainted.

24. Difficulties of Transmission.—From these facts, it becomes evident that the transmission of articulate speech between two distant points by any means whatsoever is a problem involving difficulties far greater than those of telegraphy, where transmission of single waves or impulses following each other in the proper succession is all that is required. In telephonic transmission, not only must the constantly varying rate and amplitude of vibration be faithfully reproduced at the receiving end of a line, but the fundamental tone and all the overtones must be reproduced, giving each its proper value and without altering the phase relations between them.

HISTORY AND FUNDAMENTAL PRINCIPLES OF TELEPHONY

EARLY EXPERIMENTS

25. The successful production of the telegraph by Prof. S. F. B. Morse, in 1838, was the forerunner of the telephone, as it formed the first practical application of electricity to the transmission of intelligence. The successful speaking telephone was not, however, produced until 1876, nearly 40 years later. Although many attempts were made previous to that year, they were unsuccessful, because the electrical principles involved, as well as the laws of acoustics, were evidently not thoroughly understood by the experimenters. To follow briefly these experiments is not only interesting but instructive, in that they show many points that must be avoided in the design of successful telephone instruments.

BOURSEUL'S PROPOSED METHOD

26. In 1854, a Frenchman, Charles Bourseul, proposed a method for the actual transmission of speech between distant points, which, but for one error, would have produced, if followed out, a practical speaking telephone. His

words were as follows: "Suppose that a man speaks near a movable disk sufficiently pliable to lose none of the vibrations of the voice, and that this disk alternately makes and breaks the current from a battery; you may have at a distance another disk which will simultaneously execute the same vibrations. * * * It is certain that in a more or less distant future, speech will be transmitted. I have made experiments in this direction; they are delicate, and demand time and patience, but the approximations obtained promise a favorable result."

REIS'S EXPERIMENTS

27. In 1861, Philip Reis, following somewhat closely the ideas set forth by Bourseul, produced a set of instruments that were capable of transmitting musical tones with considerable accuracy, and it is also possible that the actual transmission of speech was also accomplished. If speech was not transmitted, it was simply because Reis did not adjust his instruments properly. The principles of Reis's apparatus are shown in Fig. 9. The receiver is represented

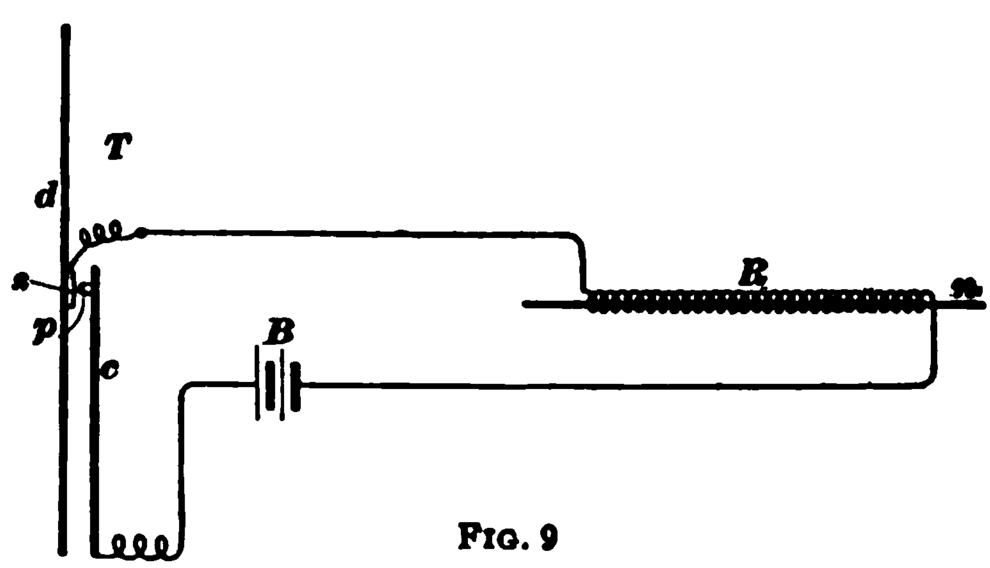


FIG. 9

at *R* and the transmitter at *T*. The transmitter consisted of a thin membrane or diaphragm *d* mounted in an opening of a rectangular box, as shown in Fig. 10. A mouthpiece *m* was provided in one side of the box, into which the sounds to be transmitted were directed. The vibrations set up in the air caused the diaphragm to vibrate to and fro in the manner already described. Carried on the diaphragm *d* was a thin copper strip *s* going to a platinum disk at the center of the

diaphragm. Almost touching this disk was a platinum contact point fixed to a stationary piece of copper *c* fastened to the box. Now, as the diaphragm vibrated up and down, the platinum disk alternately made and broke contact with the platinum point.

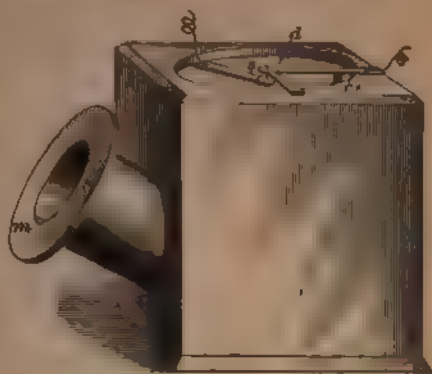


FIG. 10

The receiver *R* consisted of a knitting needle *n*, on which were wrapped many turns of insulated wire. The needle was mounted in a box of resonant wood, as shown in Fig. 11.

28. Action of Reis's Apparatus.—The action of this receiver was based on a fact pointed out by Page in 1837, that a rod of iron suddenly magnetized or demagnetized would emit certain sounds, or clicks, due supposedly to a rearrangement of the molecules caused by the changes in magnetism. This is known as the Page effect. It is also known

FIG. 11

that the magnetization of a rod causes it to become slightly longer, due probably to the same molecular rearrangement. The box in which Reis mounted his receiver served as a sounding board to amplify any sounds produced by changes in the magnetism of the needle. These two instruments were connected in one circuit, together with a battery *B*, as

shown in Fig. 9. At each vibration of the diaphragm *d*, the circuit through the battery was made and broken, thus allowing impulses of current to flow through the coil surrounding the knitting needle. This, of course, alternately magnetized and demagnetized the rod, thus producing a sound having exactly the same rate of vibration as the diaphragm.

Reis thus followed the method pointed out by Bourseul, and in doing so made the same error that Bourseul had made. This was in so adjusting his instrument that the vibrations of the diaphragm caused the contact points to make and break the circuit alternately instead of maintaining the contact at all times, and merely causing variations in pressure between them by the vibrations of the diaphragm. As long as the instrument was adjusted to make and break contact, it could transmit the pitch of the fundamental note, but not relative loudness or timbre. This instrument does not transmit variations in loudness, because the electric current always rises to the same maximum value, and again falls to absolute zero as the contact is made and again broken. It does not transmit timbre, because the circuit is made and broken just as many times per second as there are vibrations in the fundamental note, there being no means whatever for transmitting the vibrations of the large number of overtones which must accompany articulate speech. However, his so-called Page receiving instrument, Fig. 11, if connected to a properly adjusted transmitter, can be made to reproduce fairly well not only the pitch of the fundamental, but also the timbre and loudness. With this type of transmitter, a battery in the circuit is necessary.

It hardly seems possible that Reis, in the elaborate series of experiments that he undoubtedly made, could have avoided such an adjustment as would have maintained a constant contact between the platinum points and the copper strip *c* and still have allowed the diaphragm to vibrate, thus causing variations in pressure between the contact points without actually breaking the circuit. The fact remains, however, that Reis's invention was not brought to a practical degree of perfection, and remained in obscurity for a period of 15 years.

In 1876, Prof. Alexander Graham Bell and Prof. Elisha Gray, both Americans, filed in the United States Patent Office on the same day, and almost at the same hour, their applications for patents on speaking telephones, each of which contains the elements now embodied in our perfected apparatus.

BELL'S EARLY INSTRUMENTS

29. The first form of instrument constructed by Bell, in 1876, was the so-called harp of steel rods shown in Fig. 12. This instrument consisted of a number of steel rods *H*, varying gradually in length, attached to one end of a permanent magnet *NS*. A single soft-iron core, over which was wound a single coil of insulated wire, was fastened to the other pole of the permanent magnet. The receiving and transmitting instruments are exactly alike, and it should be noticed that no battery is used.

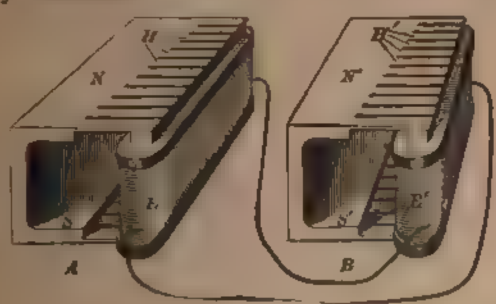


FIG. 12

Consider *A* as the transmitting instrument. When any one of the rods of *A* is thrown into vibration sympathetically by a simple sound wave in the surrounding air, the distance between the rod and core is varied. The variation in this distance causes a similar variation in the reluctance of the magnetic circuit, which in turn causes the number of lines of force to increase as the distance decreases, and to decrease as the distance increases, thereby generating in the coil of wire *E* surrounding the core a simple alternating electromotive force, and this electromotive force causes a simple alternating current, having exactly the same

frequency as that of the simple sound wave, to flow through the circuit. This current circulating through the coil *E'* will increase and decrease the magnetism of the core inside it, and cause to vibrate only that rod which, on account of its length and size, has naturally exactly the same pitch as the vibrating rod at *A* that caused this current. This rod is said to be set into vibration sympathetically with the changes in magnetic strength of the iron core of *E'*. Not only have the two rods the same pitch, but the amplitude of vibration of the first determines the amplitude of vibration of the second, because the more vigorously the first vibrates, the greater will be the maximum value of the current generated, and therefore the greater will be the variation in the pull between the core and the rod at *B*. Therefore, one rod

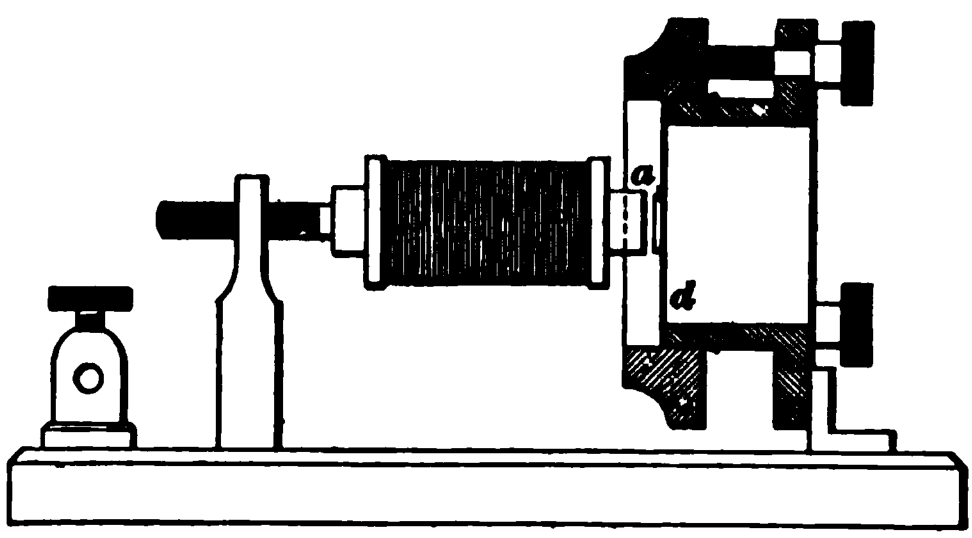


FIG. 13

is able to transmit not only pitch, but a variation in loudness. By having a large number of rods—one for each note on the piano, for instance—musical sounds could be fairly well transmitted. Furthermore, if there could be as many rods in each instrument as there are different pitches, within the limits of audibility, then speech could be transmitted, for it is evident that then any number of possible pitches, each with any degree of loudness, could be sympathetically taken up by the rods at *A* and given out by the corresponding rods at *B*, with the same relative loudness. To successfully accomplish this, however, would require an infinite number of rods, which would render the instrument utterly impracticable. It should be understood that no battery is necessary with these permanent-magnet instruments.

30. Two more of Bell's early instruments are shown in Figs. 13 and 14. The transmitter shown in Fig. 13 consisted of a double-pole electromagnet (not a permanent magnet) mounted in a horizontal position in front of a vibrating diaphragm *d* of gold-beater's skin, carrying a small soft-iron armature *a* glued to its center. This diaphragm was tightly stretched across a framework having an opening for a mouthpiece, and when set in vibration by the sound waves, caused the armature *a* to move alternately toward and from the poles of the electromagnet. The receiver consisted of an electromagnet *m*, Fig. 14, mounted vertically in a hollow soft-iron cylinder *n*. The top of this cylinder was almost closed by a thin sheet-iron disk, secured only at one side of the cylinder and slightly sprung away from its upper edge, so as to be free to vibrate when acted on by the electromagnet. The lower end of the cylinder was closed by an iron disk, to which the lower end of the magnet core was attached in such a manner that the magnetic circuit was rendered complete, except

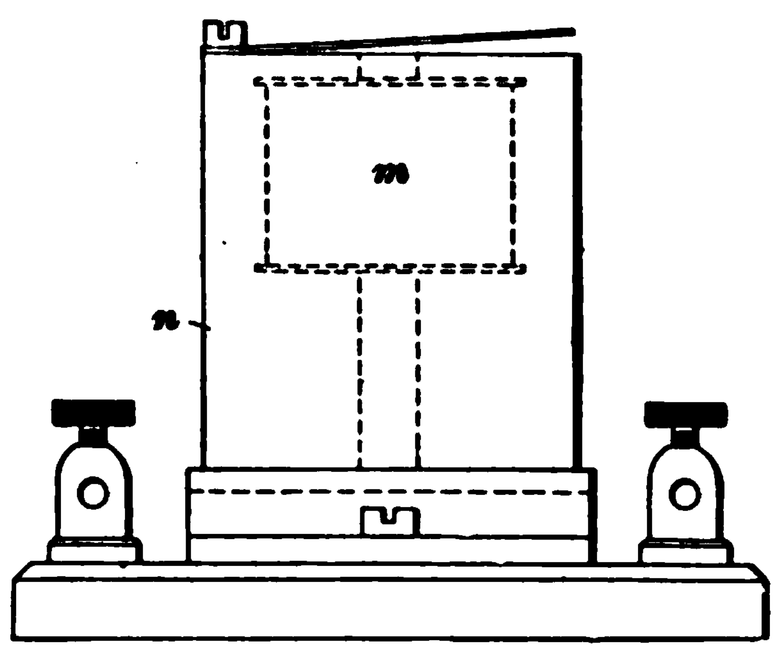


Fig. 14

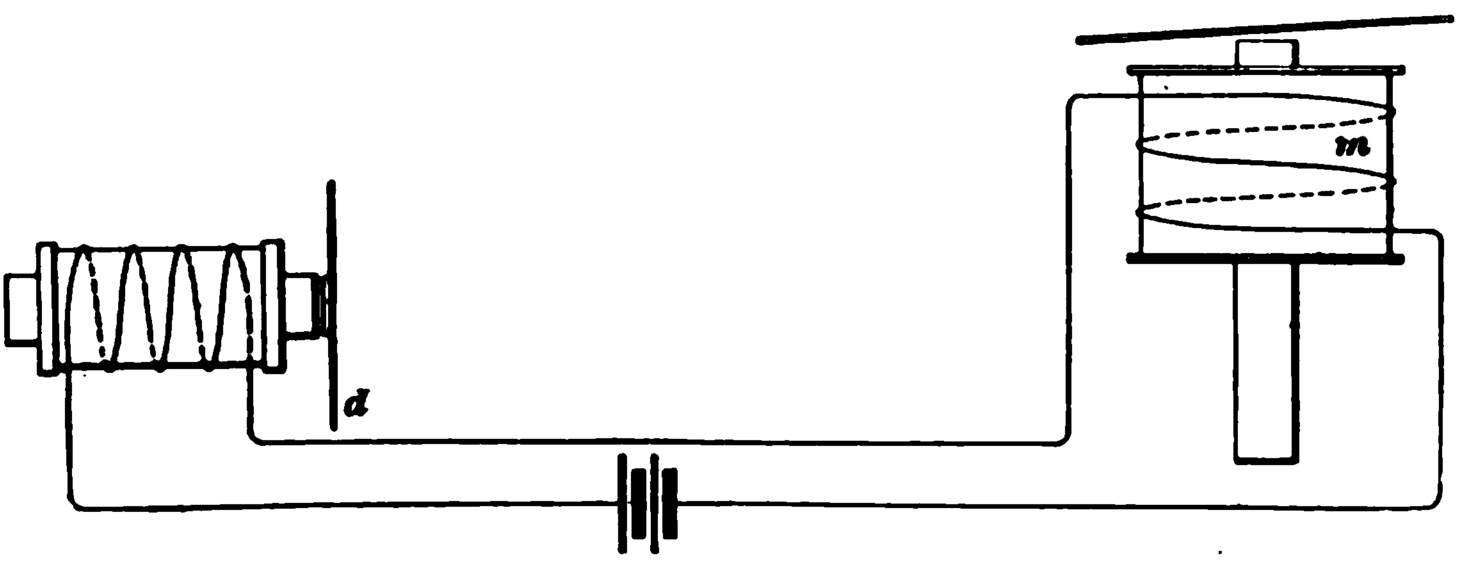


Fig. 15

for the slight break between the diaphragm and the core. These two instruments were connected in series in the same circuit with a battery, as shown in Fig. 15. A battery is always

necessary whenever a simple, non-polarized electromagnet is used in a transmitter. These instruments and this particular arrangement of the circuit formed Bell's famous exhibit at the Centennial in Philadelphia in 1876, which was the introduction of the speaking telephone to the general public. Soon after, this apparatus was somewhat modified, the diaphragm of both receiver and transmitter being made of a thin disk of sheet iron and the core of the electromagnet permanently polarized, it being, in fact, a permanent magnet in itself.

It is interesting to note that Bell first tried a permanent-magnet instrument, the harp of rods, without a battery, then electromagnetic instruments requiring a battery—his transmitter and tubular receiver exhibited at the Philadelphia Centennial—and finally, permanent-magnet instruments, but with sheet-iron diaphragms for both the transmitter and the receiver. This is one of the most remarkable pieces of apparatus ever devised. It comprises the simplest form of electric telephone, and may be used as either a transmitter or a receiver.

THE MAGNETO-TELEPHONE

31. A **telephone transmitter** is an instrument that takes up the vibrations of the sound to be transmitted and causes corresponding fluctuations of electric current to flow in the circuit in which it is connected.

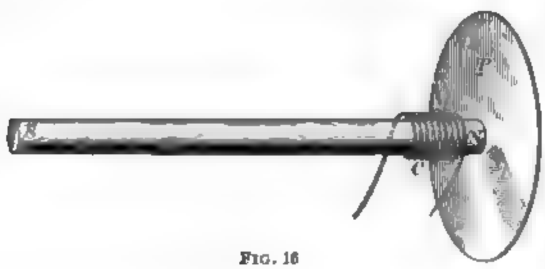


FIG. 16

A **telephone receiver** is an instrument that receives fluctuating currents corresponding to sound waves and translates them into distinguishable sounds.

The action of Bell's instrument will be understood by reference to Fig. 16, in connection with the following description.

32. Action as a Receiver.—A thin diaphragm *P* is mounted close to, but not touching, one pole of the permanent magnet *NS*. A coil of fine wire *C* is wound around one end of the magnet, and the terminals of this coil are connected directly in the circuit in which the instrument is to be used.

It is evident that the diaphragm will normally be strained slightly toward the magnet by the attraction of the latter. If a current is sent through the coil in such a direction that the lines of force set up by it coincide with those of the permanent magnet, the strength of the magnet will be increased and the diaphragm will be pulled still closer to the pole. If, however, a current is sent through the coil in such a direction as to set up lines of force opposing those of the magnet, the strength of the magnet will be diminished and the diaphragm allowed to spring farther from the pole.

If a current that is undulatory, but always in the same direction, is sent through the coil, the lines of force induced by it in the magnet will increase while the current is increasing and will decrease while it is decreasing. Thus, whether the lines induced by the coil are in the same direction as those of the magnet or not, the varying pull on the diaphragm will cause vibrations in the latter that will be in harmony with the changes in current.

Again, if the current is an alternating one—one that flows first in one direction and then in the other—the lines set up by it in the magnet will change their direction every time the current changes its direction. They will thus, while flowing in one direction, add to the strength of the magnet, and while flowing in the other, diminish it, thus producing a similar variation in attraction between the core and the diaphragm, as in the case of the undulatory current.

33. Action as a Transmitter.—While an alternating current sent through the coil will cause the diaphragm to vibrate, the converse of this statement is true; that is, if the diaphragm of the instrument is caused to vibrate by some

external means, corresponding alternating currents will flow in the coil—provided, of course, that its circuit is closed and that there is no battery in the circuit. This is true because the movement of the diaphragm toward the pole of the magnet increases the number of lines of force passing through the coil, for it is a well-known fact that changing the number of lines of force through a closed circuit will cause currents to flow in that circuit. Similarly, when the diaphragm moves from the pole, the number of lines passing through the coil will diminish and thus cause a current to flow in the opposite direction. Thus, for an outward movement of the diaphragm, we will have a current in the coil in one direction, and for an inward movement a current in the other direction.

34. Mutual Action of Two Instruments.—Two instruments like that shown in Fig. 16, if connected in one

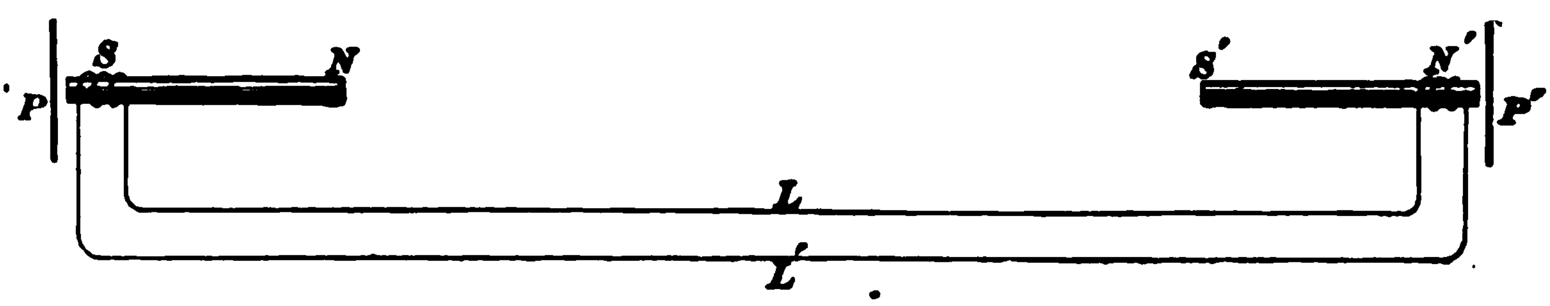


FIG. 17

circuit, as shown in Fig. 17, represent the apparatus and arrangement of Bell's improved telephone.

When the soft-iron diaphragm P is spoken against, it takes up the vibrations of the sound waves, and thus causes changes in the strength of the magnetic field in which the coil lies. These changes, as shown above, cause currents, first in one direction and then in the other, that is, an alternating current to flow in the circuit. These currents vary in direction, strength, and frequency of alternation in every way in unison with the movements of the diaphragm, and therefore have all the characteristics corresponding to the relative loudness, pitch, and timbre of the sound that caused the diaphragm to vibrate.

Passing along the line wire, these feeble currents alternately strengthen and weaken the permanent magnet at

the other instrument and cause it to exert a varying pull on the diaphragm, which thus vibrates in unison with the changes in current, and therefore faithfully reproduces the first sound. The action described as taking place in the instrument spoken to is that of a transmitter, and that in the instrument which repeats the sound is that of a receiver.

35. The instrument consisting of a permanent magnet, a coil, and a vibrating iron diaphragm is called a **magneto-telephone.** Many forms of this instrument have been devised, but all contain the same essential parts, though frequently these parts are duplicated.

36. Sensitiveness.—As a receiver, the magneto-telephone is marvelously efficient and one of the most sensitive instruments known in science. Its sensitiveness depends a great deal on its construction, adjustment, and the frequency of the current. Houston and Kennelly state that with an ordinary Bell receiver an alternating-current strength of $\frac{1}{1,000,000,000}$ ampere caused a distinctly audible sound. For this determination, an alternating current of 640 periods a second, which was determined to be the best rate for detecting feeble currents, was used.

In 1887, W. H. Preece determined that a Bell receiver would respond to a current of $\frac{6}{10,000,000,000,000}$ ampere, or six ten-thousand-millionths of a milliampere. Lodge has quite recently stated that the energy required to work his telephone, which is about 30 times as sensitive as an ordinary one, was a millionth of a millionth of a watt for giving an audible signal. For ordinary transmission, about $\frac{1}{10}$ milliampere is necessary in an ordinary receiver.

As a transmitter, however, the magneto-telephone has not proved generally successful, as the amount of energy derived from the sound waves is so extremely small that the currents generated by the movements of the diaphragm soon become lost when transmitted over lines of considerable length.

However, the magneto-instrument used as a transmitter generates a current which almost perfectly represents the

sound striking its diaphragm, in pitch and timbre, thus insuring remarkable clearness or distinctness, although at the sacrifice of loudness in the reproduced sounds. Low speech can be readily understood by any person not hard of hearing, if it is only distinct or clear. Of course loudness is a very desirable feature, especially where other disturbing sounds not coming from the telephone receiver are present.

THEORY OF MAGNETO-INSTRUMENTS

37. The permanent-magnet receiver is a great improvement over the electromagnetic instrument. The magnitude of attraction or repulsion between the core and the diaphragm depends not only on the strength of the varying current, but also on the strength of the permanent magnet. The stronger this magnet is the better, provided that the diaphragm is far from being magnetically saturated, for then a given change in the current would have less effect on the diaphragm. What is desired is to produce as great a movement of the diaphragm as possible by a given variation in the current. Now, the force of attraction between the diaphragm and the pole varies as the square of the magnetic force between them. If H is the steady magnetic force due to the permanent magnet and if the fluctuating force varies from $+h$ to $-h$, then, at one extreme position, the force between the diaphragm and the magnet is proportional to $(H+h)^2$, and at the other extreme position it is proportional to $(H-h)^2$. The maximum variation in the force is then proportional to the difference between these two values. $(H+h)^2-(H-h)^2 = 4Hh$. Therefore, the variation in the force is proportional to the quantity $4Hh$, that is, to four times the product of the permanent and variable magnetic forces. From this consideration alone, it would appear that by indefinitely increasing the strength of the permanent magnet, the force of attraction and repulsion, and therefore the amount of motion of the diaphragm and the loudness of the sound, could be indefinitely increased. But as the diaphragm approaches magnetic saturation, there will be a loss

instead of a gain by increasing the strength of the permanent magnet, because when the number of lines of force is very large, causing either the soft-iron core or the diaphragm or both to be magnetically saturated, a variation of the current in the coil will alter the number of lines of force through the magnetic circuit by an imperceptible amount. Consequently, the force exerted between the diaphragm and the soft-iron core will change by an imperceptible amount. To prevent saturation of the diaphragm is one reason why large, powerful magneto-instruments require larger and, especially, thicker iron diaphragms.

If no permanent magnets were used at all, then, even if h, the variable force, was very large, a very inferior instrument would be the result. It would probably be indistinct, due to rattling of the diaphragm, because the constant tension on the diaphragm produced by a permanent magnet would be absent. For a transmitter using powerful magnets, a comparatively large and thick diaphragm, and for receivers a ferrotype or thin iron, have proved to be the best.

In regard to the motion of the diaphragm, the original, and perhaps natural, idea was that it vibrated in nodes and loops only, but by experiment it has been shown that there is a swelling in and out at the center. However, it does not appear conclusive because its vibrations in and out only are visible and measurable, that there may not at the same time be some imperceptible node and loop vibrations. Du Moncel thought that the sound was originally caused solely by the Page effect (see Art. 28), and that this effect was then strengthened by the diaphragm. This explanation has been shown to be insufficient, although instruments have been made to work, but very feebly, without any diaphragm. Molecular changes therefore appear to play some part in the action.

In the receiver now used, the shell shields the diaphragm from extraneous sounds, and the very thin air space between the diaphragm and the mouthpiece avoids disagreeable resonance effects. There are no aftertones in a magneto-receiver; that is, the diaphragm does not tend to take up a period of

vibration of its own, and so continue to vibrate, depending on its natural rate of damping to come to rest after its forced vibrations produced by the variable currents in a receiver or by the air waves in a transmitter have stopped. For the magnet itself is a damper, because if the diaphragm did not immediately come to rest, it would be generating by its motion either a current in the coil or eddy currents in the magnet and diaphragm, which currents would be flowing in such a direction as to oppose the motion producing them, and these currents would also require the expenditure of energy to generate them; but there is no external source of energy to keep the diaphragm vibrating, and therefore it must come to rest instantly.

To attain the best results, there is a best strength for the permanent magnet; a soft-iron core, only long enough to pass through the coil, should be fastened to the permanent magnet, and the coil should be located on this core where the change in the number of lines of force at right angles to the winding is greatest. Neither the soft-iron core nor diaphragm should be nearly magnetically saturated, and there is a best diameter and thickness of the diaphragm for a given strength of the permanent magnet. Five thousand periods per second produces about the highest tone to which an ordinary receiver will respond.

BATTERY TRANSMITTERS

38. While the magneto-telephone is capable of transmitting speech with great distinctness, preserving with great accuracy the quality of the tone, it is not well adapted for a commercial transmitter, its action being so feeble as to render transmission over long distances very difficult. To overcome this difficulty, a class of instruments depending on an entirely different mode of operation was devised. These instruments, instead of causing the transmitter to act as a generator of electricity, served to produce variations in the strength of a current already supplied by some other source. The **battery transmitter** may therefore be said to act as

a valve in the circuit, the valve itself requiring but little energy to operate it, but capable of controlling a far greater amount of energy flowing from the battery.

GRAY'S WATER TRANSMITTER

39. The first battery instrument was devised by Elisha Gray and formed a part of his early telephone. This is shown in Fig. 18, in which D is a vibrating diaphragm, carrying at its center a needle point p of platinum, immersed in a fluid of rather low conductivity, such as slightly acidulated water. The other terminal of the transmitter is formed by a similar needle q projecting into the fluid from below. Vibrations of the diaphragm cause the needle p to vary the length, and therefore the resistance, of the path from one point to the other through the liquid. The variations in resistance thus brought about by the vibrations of

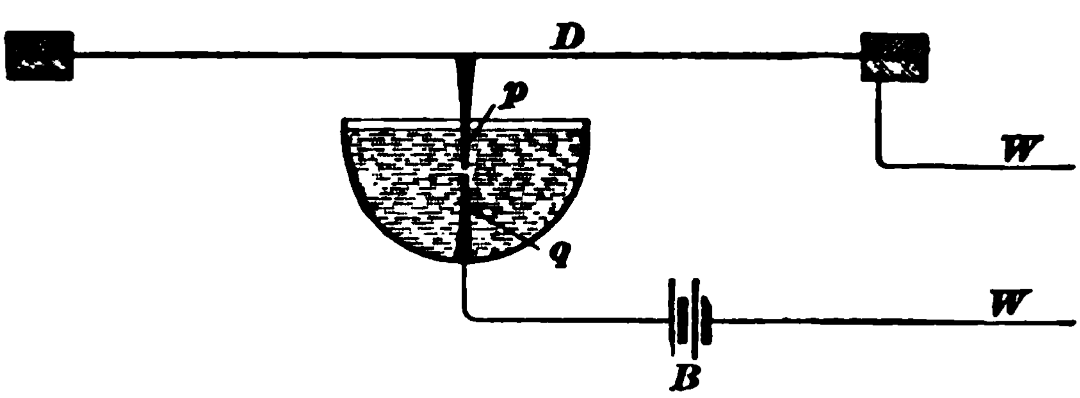


FIG. 18

the diaphragm cause corresponding variations in the current from the battery B connected in the circuit, which variations are then capable of acting on the receiver connected with the wires W, W, in precisely the same manner as has been described. The results obtained from the water transmitter were scarcely better than those from the magneto-transmitter, and it had obvious disadvantages due to the necessary presence of a liquid, and therefore never came into commercial use. It was, however, the first transmitter constructed embodying the idea of causing the vibrations of the diaphragm to vary the strength of the current by changing the resistance of the circuit in which it was flowing. It was not long before a far better way was found of producing this variation in resistance, and this was by the

vibration of the diaphragm to produce a variation in pressure between two electrodes or terminals in constant contact, the variation in pressure effecting a corresponding change in the resistance at the contact surfaces, and therefore a change in the total resistance of the circuit.

BERLINER'S TRANSMITTER

40. A patent, covering broadly this form of transmitter, has been granted to Emile Berliner, who produced the apparatus in 1877, but did not obtain his patent until 1894. **Berliner's transmitter** is illustrated, in principle, in Fig. 19, in which D is a diaphragm of ordinary tinned iron resting against a ball E carried on a thumbscrew. This thumbscrew is mounted in a bracket C in such a manner as to afford a means for adjusting the pressure between the diaphragm and the ball. Variations in pressure between the diaphragm and the ball cause corresponding variations in resistance, and thus produce similar fluctuations in the current strength. In Berliner's first transmitter, the diaphragm was about 4 inches in diameter, of ordinary tinned iron and mounted very roughly over an opening in a wooden box. The back contact consisted simply of a blued-iron woodscrew. There has been much discussion as to whether or not this instrument ever actually transmitted speech, but it is certain that it was not a transmitter suitable for practical use.

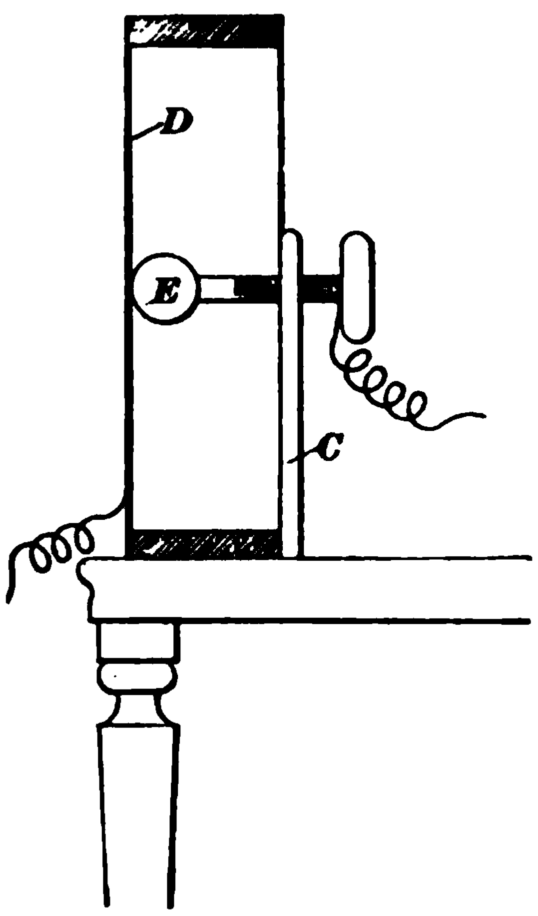


FIG. 19

EDISON'S CARBON TRANSMITTER

41. Soon after the production of Berliner's instrument, it was found by Edison, as a result of experiments with various semiconductors, that carbon was by far the most

suitable material for the electrodes of such a transmitter. One form of **Edison's transmitter** is shown in Fig. 20; in which *D* is the vibrating diaphragm, against which presses a small button *K* of ivory, having attached to its rear face a thin platinum disk *h*. In the rear of the casing of the instrument is an adjustment screw *E* having an enlarged head *e*, which carries on its front surface another thin disk of platinum *f*. Between these two disks is placed a cylindrical button *g* of compressed lampblack. The two platinum disks form the electrodes of the transmitter, and it is evident that the vibrations of the diaphragm are transmitted to the front platinum disk, thus causing it to exert a varying pressure on the button of lampblack between it and the disk *f*. These variations in pressure cause corresponding variations in resistance, and therefore, according to Ohm's law, transform the steady current that would be flowing when the transmitter is not in motion into an undulating current. Transmitters of this type produce undulating currents and not alternating currents, such as produced by the Bell magneto-instrument when used as a transmitter. An undulating current may be defined as a current whose strength fluctuates, but whatever may be the strength of the current, it always flows in the same direction through the circuit.

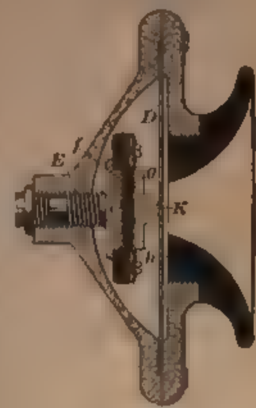


FIG. 20

HUGHES'S DISCOVERIES

42. Electrodes in Loose Contact. Up to this time, the best conditions for producing changes in resistance between two electrodes by varying the pressure between them had not been realized. Prof. David E. Hughes, in 1878, by a long and interesting series of experiments, proved that the resistance of two conductors in loose contact with each other was far more susceptible to changes in pressure

than if they were pressed firmly together. He found that these laws held for any conducting material whatever, and one of his experiments consisted in producing a transmitter made from three wire nails arranged as shown in Fig. 21. In this, the nails A and B form the terminals of the circuit, which includes a battery and a receiving telephone, the circuit between these two nails being completed by nail C laid loosely across the other two. Any vibrations in the air caused corresponding vibrations of the nails, and thus produced variations in resistance at the surfaces where C came in contact with B and A.

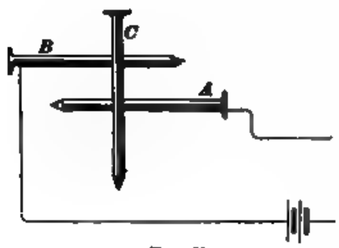


FIG. 21

43. Hughes's Microphone.—In Fig. 22 is shown another transmitter produced by Hughes, and called by him the **microphone**, because he considered that it accomplished in acoustics what the microscope did in optics. It consists of two carbon blocks b, b mounted on a diaphragm d of thin, dry wood. Supported in recesses on the upper and lower sides, respectively, of the two blocks b, b is a small carbon pencil p. The two blocks b, b formed the terminals of the circuit in the same manner as did the two nails in Fig. 21, the circuit between them being completed by the carbon pencil. Any vibrations of the diaphragm caused by sound waves produced changes in the resistance at the contact surfaces between the terminals of the transmitter, and corresponding changes in the current flowing through the circuit. This instrument proved so marvelously sensitive as to merit the name given it by its inventor. Small sounds,

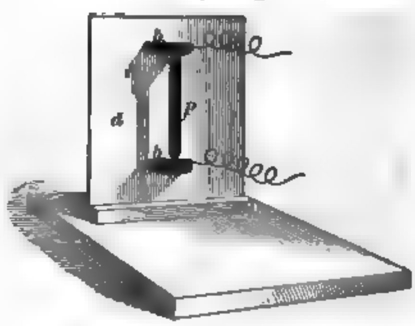


FIG. 22

such as a faint scratching on the diaphragm or on the support on which it rested, so faint as to be entirely inaudible, produced loud noises in the receiver. So delicate was this instrument, however, that it proved unsuitable for ordinary telephone transmission. Noises of moderate loudness produced such an uproar in the receiver as to entirely destroy the original quality of the sound. This is largely due to the fact that a violent vibration between the electrodes causes the circuit to break entirely at times. This defect, however, has been remedied in a number of ways, as will be seen later.

HUNNING'S TRANSMITTER

44. Granular Carbon Transmitter.—Still another step in the development of the battery transmitter was made by Henry Hunning in 1881. He introduced the idea of using granulated material, preferably carbon, in a loose state, as the variable resistance medium of transmitters, and all the so-called long-distance instruments now employ this feature. Hunning's original device was very similar to that shown in Fig. 23. Clamped between the wooden block *B* and the mouthpiece *A*, which may also be of wood or of hard rubber, is a thin diaphragm *D* of some elastic non-corrosive conducting material. Hunning used a platinum diaphragm, but this, on account of its high cost, has generally been superseded in a large class of instruments by a diaphragm of thin carbon or other material. Within the chamber behind the diaphragm is mounted a block of carbon *C*, and the space between this and the diaphragm is filled, or partly filled, with granulated carbon, resembling in appearance ordinary gunpowder. Finely pulverized carbon was at first used, but this packed

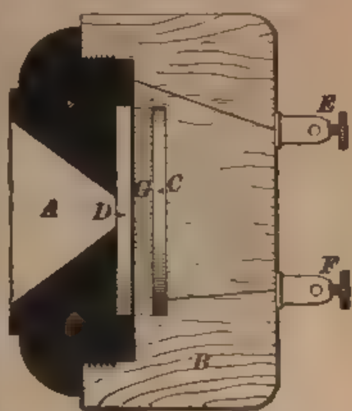


FIG. 23

so easily that it was soon superseded by the granulated carbon. The two binding posts *E*, *F* are connected, respectively, with the diaphragm and with the carbon block, the circuit between them being completed by the carbon granules. In this, we have a large number of loose contacts between the granules and the diaphragm, between the granules and the back block, and also between the granules themselves. The sound waves entering the mouthpiece produce vibrations of the diaphragm, which vary the pressure at the multitude of loose contacts, and thus vary the resistance of the circuit.

THEORY OF MICROPHONE TRANSMITTER

45. The action of the **microphone transmitter** has been, and still is, the subject of much discussion by scientists. Four explanations have been advanced as to why a change in the pressure between two electrodes of carbon or of other material produces the wonderfully sensitive effects on the resistance through the point of contact.

46. Changes in Actual Resistance of Carbon.—The first of these theories is based on the supposition that carbon in itself has the property of changing its resistance when subjected to pressure, the resistance becoming lower as the pressure is increased. It was on this supposition that the early transmitters of Edison, using carbon as the variable resistance medium, were constructed. It has been proved, however, that the resistance through a rod of carbon is not changed perceptibly by increasing the pressure up to the crushing point of the carbon.

47. Occluded-Air Theory.—The second theory is one set forth by Mr. Berliner. It is that the surfaces of the electrodes are held slightly apart by a thin film of air that collects over the entire surface of the electrodes and therefore prevents actual contact between them.

In order to accept this theory, we must believe that the air that is occluded on the surface of the electrodes possesses different characteristics from the air with which we

are generally acquainted. A layer of air in its ordinary state, as thin as physical means can produce, will have a very large resistance, and as the resistance of a microphone contact is not large, it follows that this ground is not tenable. If, however, the air is in some different state, it may be that it possesses conducting properties to some degree. Under this view, Berliner's theory does not seem altogether improbable, and the possibility that air might, under certain conditions, possess these properties is not denied by prominent physicists. Were it the case, however, that the electrodes were thus held apart by a film of air, the conditions would be similar to that of two conducting bodies immersed in a conducting fluid. It is found

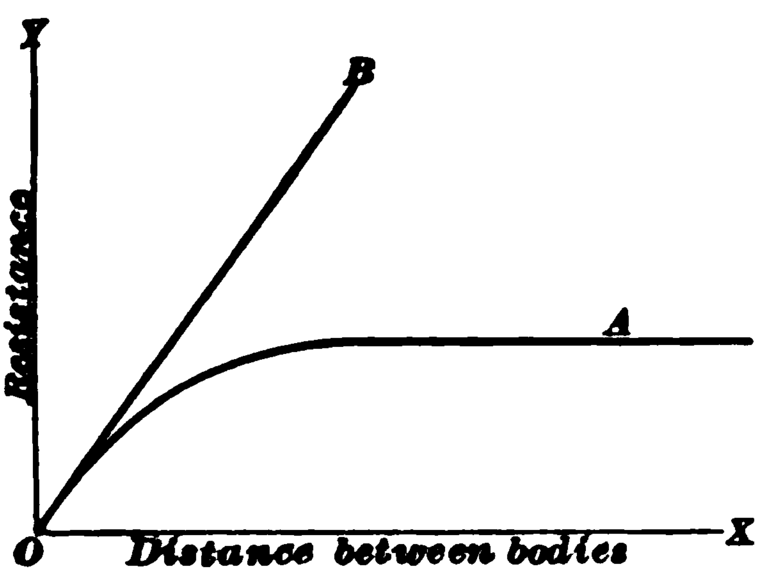


FIG. 24

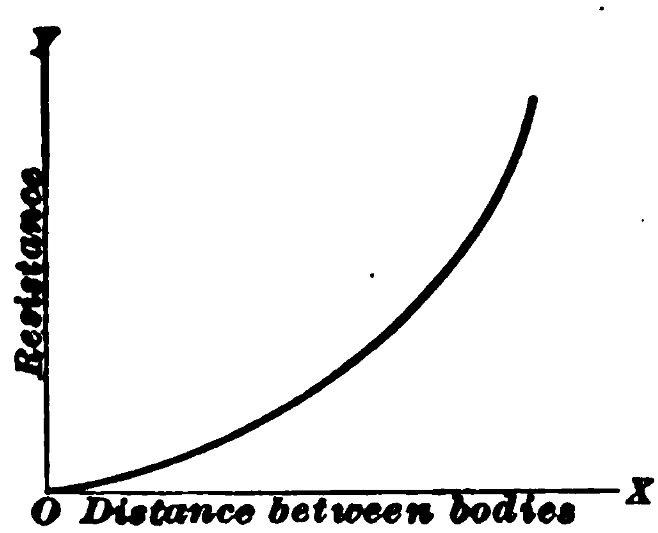


FIG. 25

by experiment that the resistance between two such bodies is unaffected by the distance between the bodies, provided that they are of small size in comparison to the cross-section of the liquid. If, therefore, a curve is plotted as shown in Fig. 24, representing the distance between the bodies on the horizontal line X and the corresponding resistances between them on the vertical line Y, it will assume the form shown at A, the resistance gradually increasing as the two bodies are separated, but soon becoming a constant, regardless of the distance between them. This latter condition is shown by the flat portion of the curve. If the conducting bodies were flat plates and the distance between them very slight as compared with their diameters, the curve might assume the form of a straight line, as shown at B

in Fig. 24. In this case, the resistance would vary directly as the distance between the plates increased.

The actual behavior of the resistance of the microphone contact determined experimentally shows that the curve is always of the general form shown in Fig. 25. This curve shows the relation between the increase in distance through which the electrodes move and the corresponding increase in resistance. It is seen that this curve is of the opposite nature from that which we would expect were Mr. Berliner's theory of occluded air true. It therefore seems probable that this is not the correct theory of the microphone.

48. **Heating Effect at Contact.**—The third theory is that the heating effect, due to the passage of a current through the point of contact, in some way aids the microphonic action. It has been shown, by examination of the microphone contact under a microscope, that small arcs were present at the point of contact. It is not clear, however, how these arcs or how the heating effect without the arcs would prove otherwise than detrimental to good transmission.

Some hold that an increase in current, due to a decrease in resistance brought about by an increase in pressure, would cause the particles at the point of contact to become hot, and thus further reduce the resistance. It is true that carbon possesses the peculiar property of lowering its resistance when heated, and it is also undoubtedly true that such an action would take place were the electrodes allowed to remain in one position long enough. It is well established, however, that the rise in temperature following an increase of current is a comparatively slow process, and it is therefore not probable that the decrease in resistance due to the increase in temperature would take place in time for it to be of any particular advantage. On the other hand, it would seem that if this action takes place to any appreciable extent, it would prove detrimental to transmission, because the changes in resistance due to the changes in temperature would lag to an appreciable extent behind the changes in

pressure. This would of course tend to destroy the form of the wave and therefore produce changes in the timbre or quality of the voice at the receiving station.

49. Theory of Surface Contact.—The fourth theory is that the changes in resistance brought about by changes in pressure between the microphone contacts are due to changes in the actual area of the contact. The fact that such changes in the area of the surface contact do take place may be well illustrated by pressing a white billiard ball, or similar body, lightly against a marble slab previously given a thin coating of graphite. On removing the ball, the area of contact will be represented by a small-sized dot of graphite on it. If, now, the ball is dropped from a considerable height on the slab and caught in the hand as it bounds upwards, it will be found that the spot of graphite resulting from the contact will cover quite a large area, thus showing that under the increase of pressure the surface of the ball was flattened and the surface of the marble slab indented to such an extent as to bring a considerable area of the surfaces of the two into contact. It is clear that if the two bodies were of conducting material, the resistance at the point of contact would vary in proportion to the area of contact.

That such an action as this actually takes place in a microphone contact cannot for a moment be doubted, for it is well known that carbon and other materials suitable for such contacts possess a rather high degree of elasticity, and it is certain that they are subjected by the vibrations of the diaphragm to a varying pressure. The form of the curve in Fig. 25 corresponds exactly to what would be expected from theoretical conditions alone, were all the variation in resistance due to increasing pressure brought about by the increase in surface contact. The matter has been studied carefully, and in the case of steel bicycle balls immersed in oil to prevent the occlusion of air on their surface, curves corresponding to that of Fig. 25 have been found to correctly represent the changes in resistances due to varying pressure.

50. The opinion is now held by many leading telephonists that the action of the microphone is due almost entirely to changes in surface contact, and that while some of the actions set forth in the other theories may be present to some extent, they do not in any perceptible manner modify the general result. In the case of rough electrodes, the action might be considered to be brought about by changes in the number of points of contact, but this would clearly be only another way of affecting the area of contact.

This theory is a perfectly satisfactory one, in that it is in accordance with all the experimentally determined facts concerning the action of the microphone. Apparently the chief reason for searching for more complex theories has been that our minds are loth to attribute such marvelously delicate results to such a very simple cause.

51. It has been shown by Professor Fessenden that the oxide formed by a substance to be used for a contact in a microphone transmitter must be a gas or else a conductor, if satisfactory and coherent results are to be obtained in use. This limits us to the use of the following materials: Carbon, osmium, lead, lead sulphide, manganese, and possibly impure sulphur. If, however, the materials are kept in an enclosure, then some gas, such as chlorine, may be used instead of air, and all substances forming gaseous chlorides may be used. No substance is equal to carbon, mainly because carbon is so much more elastic that the small prominences which make the contact can stand so much distortion before breaking.

If a metal is desirable as one electrode, platinum or gold is by far the best, because neither corrodes under ordinary conditions.

52. Peculiar Adaptability of Carbon.—The fact that carbon possesses the property of lowering its resistance when heated, and probably without affecting the actual microphonic action, is of great advantage in reducing the resistance of the transmitter as a whole while it is heated by the passage of currents. As the transmitter becomes hot,

due to the flow of a heavy current through it, its resistance is lowered instead of raised, as would be the case were almost any metal used; and this is advantageous, in that it reduces the total resistance of the local circuit and thereby allows a greater current to flow.

THE INDUCTION COIL IN TELEPHONY

53. Review of Microphonic Action.—In order to more readily comprehend another development that was made at an early date, the action of a variable resistance transmitter when placed in circuit with a receiver will be reviewed, reference being made to Fig. 26. In this figure, a carbon button *B* is mounted on a flexible diaphragm *D* supported at its edges in a stationary ring *A A'*, as shown. Against the button *B* rests a similar button *C*, also of carbon, carried on the spring *S*. The diaphragm and spring

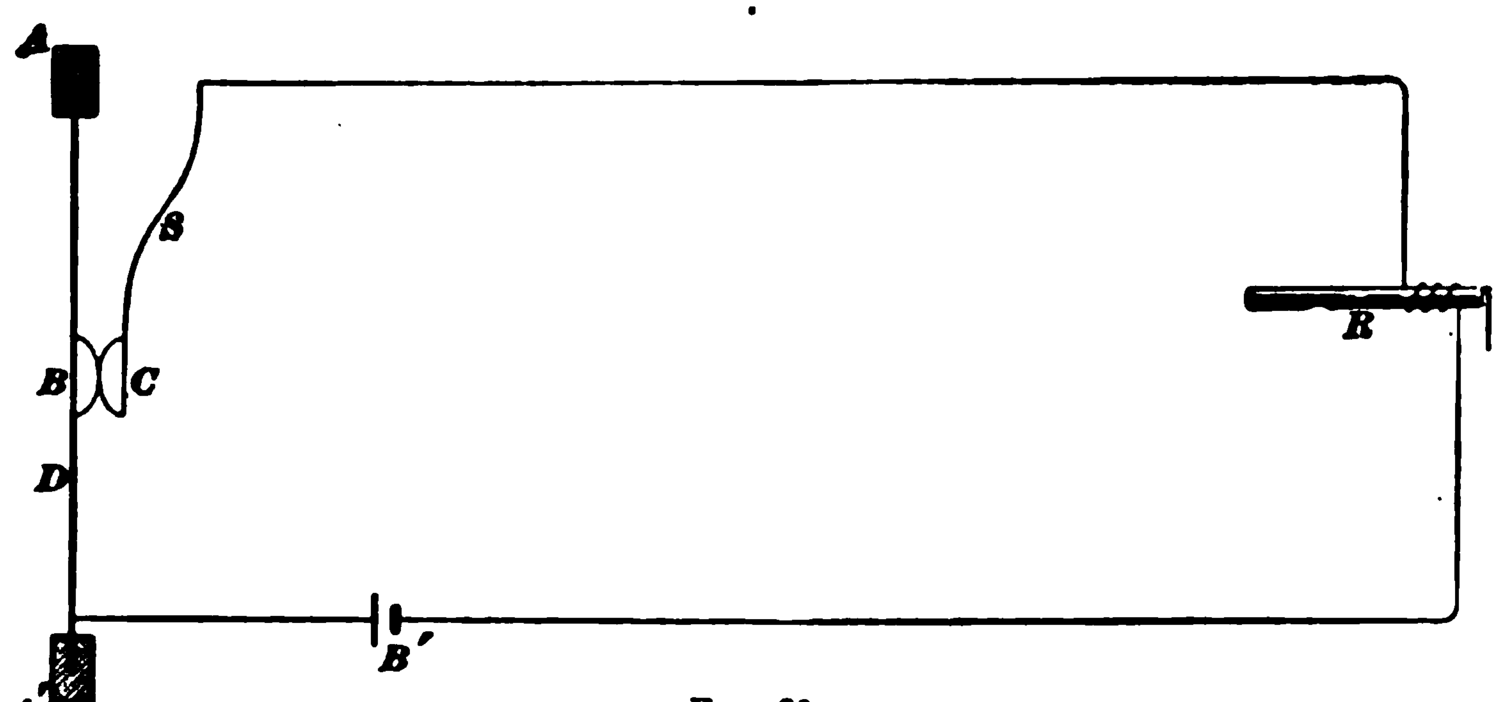


FIG. 26

form the terminals of a circuit including the receiver *R* and a battery *B'*. While the instrument is at rest, a steady current flows through the circuit, of which the two carbon buttons and the coil of the receiver form a part. If the diaphragm is caused to vibrate in the slightest degree, a variation in pressure at the point of contact between the buttons will take place, which will cause a corresponding variation in the area and therefore in the resistance of the contact. This in turn produces fluctuations in the strength

of the current, which travel along the line wire and act on the diaphragm of the receiver. Sounds, such as spoken words, uttered against the diaphragm D will cause it to vary the pressure between the buttons in such a manner as to produce fluctuations in the current flowing in the circuit from the battery B', which fluctuations will be in exact unison with the sound waves, and will therefore cause the diaphragm of the receiver to vibrate in unison with that of the transmitter. The battery transmitter therefore serves, not as a generator of electricity, as in the case of the magneto-transmitter, but as a valve to control the flow of current from another source, that is, from the battery B'.

54. Transmitter in Line Circuit.—Where a transmitter is included directly in the circuit with a line wire, as shown in Fig. 26, it is obvious that if the line is long and the resistance of its circuit comparatively high, a small fluctuation in the resistance of the transmitter will produce but a slight change in the total resistance of the circuit, and therefore will affect the flow of current in the circuit to but a slight degree. It is exceedingly important that the variable resistance in all microphone transmitters should be large compared to the total resistance of the same circuit, so that the fluctuations in the current shall be large.

To illustrate, suppose the resistance of the entire circuit to be 1,000 ohms, and that the transmitter is capable of producing a change in this resistance of 1 ohm; the transmitter will therefore be capable of producing a change in the total resistance of the circuit of one one-thousandth of its original value, and as a result the current flowing in the circuit will be changed by an amount equal to one one-thousandth of its normal value.

55. Transmitter in Local Circuit.—It is evident that a high resistance in a circuit where this arrangement is used is detrimental to powerful transmission in two ways: in the first place, the high resistance will render the normal current flowing from a given source comparatively small, and in the second place, the small ratio that the changes in resistance

brought about by the transmitter bears to the total resistance of the circuit will render the fluctuations in this already small current very slight. In order to remedy this defect, it has become common practice to place the transmitter and battery in a local circuit containing also the primary winding of a small induction coil. This is necessary in order that the resistance external to the variable contact resistance of the microphone should be small. This applies to the internal resistance of the battery, to all connecting wires, joints, and the primary winding of the induction coil. The secondary winding of this coil is placed directly in the circuit of the line wire with the receiving instrument, the arrangement of circuits being as shown in Fig. 27, in which T is the transmitter; B, the battery; P, the primary winding of the induction coil; S, the secondary winding; and R, the receiving instrument at the distant station. The resistance of the

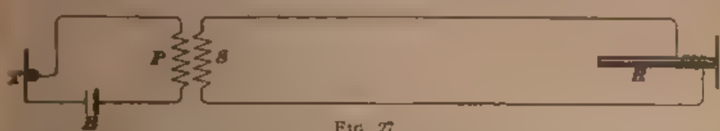


FIG. 27

local circuit in this case is usually made very low, less than 7 ohms, but we will say, for convenience, that it is 10 ohms. If the same transmitter, as in the preceding case, is used in this circuit, it will still be able to produce a change in the resistance of 1 ohm, and this change will bring about a change in the total resistance of the circuit of one-tenth of its normal value; from which it follows that the total change in the current value in the transmitter circuit will be one-tenth of its normal amount, or 100 times as great as in the case where the transmitter was included directly in the line wire. Not only will the change in current bear a far greater ratio to the normal current flowing, but the normal current itself will with the same battery power be 100 times as large, because the resistance of the circuit is but one one-hundredth of the value assumed in the previous case.

It may at first sight appear that the larger the primary current, the better would be the results at the receiver.

But it is necessary to remember that owing to the heating effect of the current at the contact points of the microphone, there is a best normal current, probably different for each kind of transmitter, above which it is not safe to increase the current. Thus, it is quite easy, by using too strong a current in the transmitter circuit, to so heat the contact that its speaking qualities are impaired, if not destroyed altogether.

56. Action Between Primary and Secondary Coils.—The primary winding of telephone induction coils is usually composed of a small number of turns of comparatively coarse wire wrapped around a bundle of soft-iron wires forming a core. The secondary winding is composed of a large number of turns of very fine wire, and is usually wrapped outside of the primary winding, therefore surrounding it and the core also. Whatever lines of force are set up in the core of the coil by the current flowing in the primary winding will pass also through the convolutions of the secondary winding. The fluctuations in the current in the local circuit of Fig. 27 will cause corresponding fluctuations in the number of lines of force set up by the current in the core of the induction coil. As these lines also pass through the secondary winding of the coil, it follows that, by the laws of electromagnetic induction, currents will be induced in this secondary winding that will correspond to the changes in the number of lines of force passing through the coils, and therefore to the changes in current strength in the primary. The current in the primary or local circuit is undulating, but not alternating; it never changes its direction. The current in the secondary, however, is alternating in character, flowing first in one direction and then in the other. This fact is usually somewhat puzzling to the student, but its explanation is very simple. When the current in the primary winding increases, due to a decrease in the resistance of the transmitter, the number of lines of force through the core of the induction coil increases. When the current in the primary decreases, the number of lines of force in the core also decreases.

It is a well-known fact that the direction of an induced current in a coil depends on whether the lines of force through that coil are increasing or decreasing in number, provided of course that the lines continue in the same direction. In the induction coil, as shown in Fig. 27, the lines of force remain in the same direction, because the current producing them does not change its direction; but they are alternately increasing and decreasing in number, and therefore the induced current in the secondary must flow in one direction as long as the lines of force are increasing, and then in the other as long as they are decreasing in number.

Telephone systems having the transmitters directly in the line circuit and supplied with current from some centrally located common battery are now in successful operation, but in such cases the transmitters are made to have a very much higher resistance than where they are connected in a local primary circuit.

INSTRUMENTS DEPENDING ON CAPACITY

57. Condenser Instruments.—There is one other type of instrument, which may be used both as a receiver and as a transmitter, that should be mentioned. It is well known that the electrostatic capacity of a simple plate condenser may be made to vary by varying the distance between the plates. Consequently, if a plate condenser be connected in series with a battery and the distance between the plates be made to vary in unison with the sound vibrations, by fixing one plate and talking against the other, its electrostatic capacity will vary, and consequently the charge will vary, causing a current varying in unison with the sound waves to flow in and out of the condenser. Evidently, if the variations in the charge are large enough and a proper receiver be connected in the same circuit, it will give out the original sounds.

A condenser instrument may serve as a transmitter or receiver. Dolbear invented a condenser receiver consisting of two thin metal disks set very close together, but not touching, of course. If these two plates are connected to

an ordinary microphone transmitter, the charges on the condenser plates will vary, since the potential at the plates will vary as the resistance in the microphone varies. This variation in the charges will cause a variation in the force of attraction between the plates, because they have on them two variable charges of opposite polarity, and therefore the plates will vibrate in unison with the original sound waves. This receiver has not proved successful, however, because it requires a very powerful microphone transmitter and induction coil, and, furthermore, it is necessary to cut out the high resistance of the secondary coil at the receiving end in order to have the sounds reproduced with sufficient intensity.

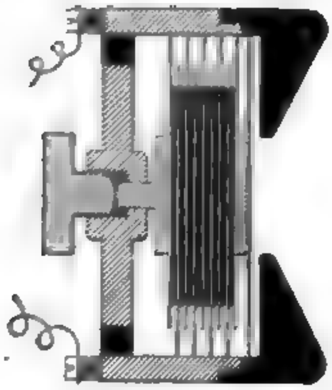


FIG. 28

In 1877, Edison developed a condenser transmitter that would work, but it required a very powerful electromotive force and consequently a large number of cells to operate it successfully. One form made by Edison was composed of very thin plates separated by paraffin paper, having a mica diaphragm with a cork button between it and the condenser, as shown in Fig. 28. When the diaphragm is set in vibration, the plates are pressed together more or less; thus, the distance between them varies, and this changes their electrostatic capacity.

THREE CLASSES OF TRANSMITTERS

58. There are, as we have seen, three kinds of variations that may be used to produce an undulating or an alternating current for the transmission of speech:

1. Variation of the magnetic reluctance in a magnetic circuit, producing an alternating or variable electromotive force in a circuit, as in a permanent magneto-transmitter.

2. Variation of the resistance in an electric circuit as in all microphones.

3. Variation of the capacity in an electric circuit, as in the condenser transmitter.

The second method has given by far the best results.

PROPERTIES OF TELEPHONE CIRCUITS

ELECTRICAL CONDITIONS AFFECTING TELEPHONIC TRANSMISSION

CURRENTS

1. Before considering the electrical conditions affecting telephonic transmission, it is necessary to consider the ordinary classification of electric currents. Any electric current may be classified either as a *direct current* or as an *alternating current.* The abbreviations for these are D. C., direct current, and A. C., alternating current.

DIRECT CURRENT

2. A **direct current** may be defined as a current that always flows in the same direction through the conductor or circuit. A direct current may be *continuous* or *pulsating.* Strictly speaking, a **continuous current** is one in which the electromotive force has an absolutely constant value during succeeding intervals of time, which would therefore cause a perfectly steady current to flow through a circuit of constant resistance.

Constant-potential dynamos, which are used for direct-current incandescent lighting, and primary and storage batteries, furnish direct currents.

A **pulsating current** is one that always flows in the same direction, but the electromotive force or resistance

varies, so that the current consists of distinct impulses, or rushes of current. Fig. 1 (*a*), (*b*), and (*c*) represents three possible curves of pulsating currents. In (*a*), the fluctuations of the electromotive force, or current, occur between a maximum and zero; while in (*b*), the minimum is about .7 of the maximum; (*c*) represents a slightly different type of curve in which the minimum is about .85 of the maximum. Either of the last two closely approaches a strictly continuous current. The curve shown in Fig. 1 (*b*) is sometimes referred to as the *alternating component* of a direct current. In this case, the resultant current may be considered as a continuous current having a small alternating current superimposed or added to it.

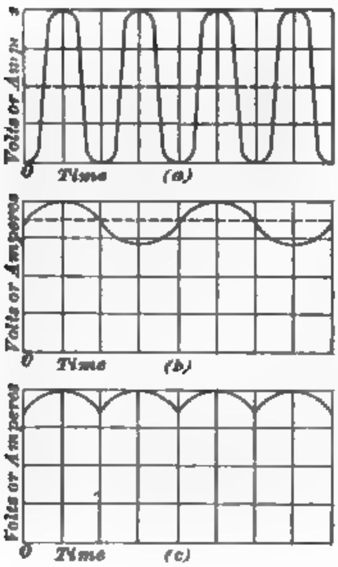


FIG. 1

Some arc-light dynamos produce a pulsating current resembling (*c*); the pulsations are so intense as to frequently cause, by induction, considerable noise or a distinct hum in circuits that run parallel and near arc-light lines.

ALTERNATING CURRENTS

3. An **alternating current** may be defined as a current that is continually reversing its direction in the circuit; consequently, the electromotive force, as well as the current, alternates between two opposite maximum values. The curve of the electromotive force, and also the curve of the current, will therefore be on both sides of the horizontal reference line, as represented by the curve *A B C D E* in Fig. 2.

4. Alternating-Current Waves.—Telephonic transmission is effected by means of alternating or undulating

currents of electricity flowing in a circuit containing the receiving and transmitting instruments. While the wave form of this current is exceedingly complex, it may be considered as being made up of a large number of simple waves,

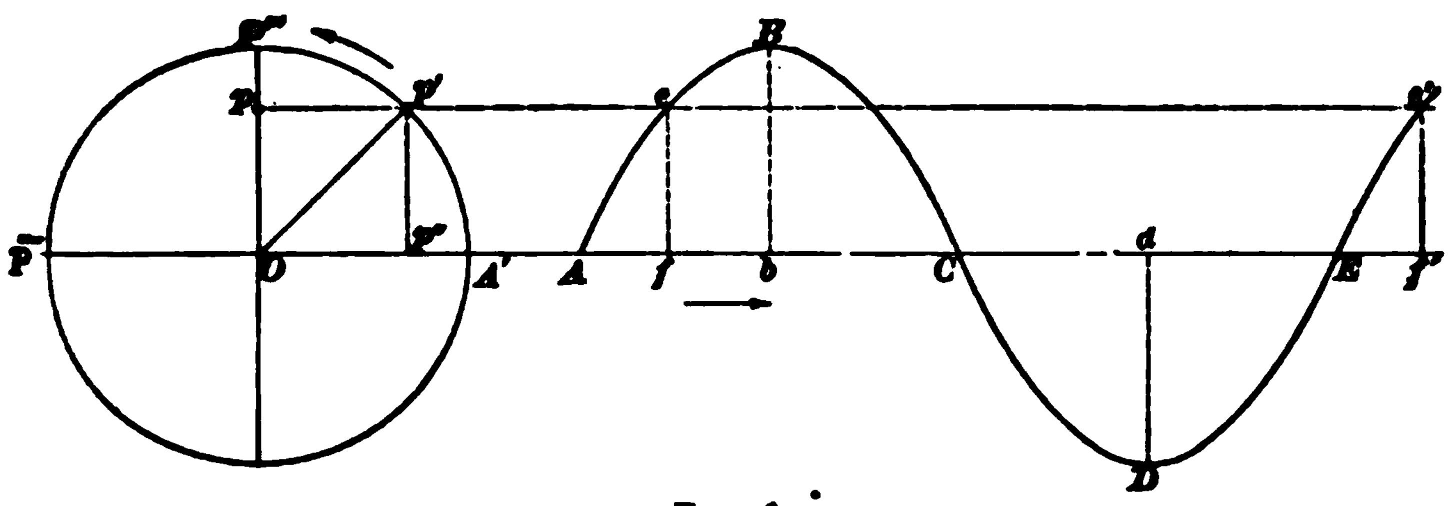


FIG. 2

each following, in its rise and fall, the law of sines. Alternating currents may be generated in many ways, the most common, in telephony, being those set up by the battery transmitter and induction coil in the ordinary telephone set, or by the magneto-generator used in generating current for calling purposes.

PROPERTIES OF CIRCUITS

5. Difficulties Preventing Perfect Transmission. Perfect telephonic transmission involves the accurate reproduction at the receiving end of the line of the sound waves produced at the transmitting end. This means that the amplitude, form, and frequency of the reproduced waves should be identical with those of the original waves. The reproduction of the sound waves without loss in amplitude involves the transmission of electrical energy with no loss in the line or other parts of the circuit; i. e., with an efficiency of 100 per cent. This is an impossibility. The exact reproduction of the form of the wave involves the transmission, not only of the wave corresponding to the fundamental tone, but of those of higher frequencies corresponding to the overtones, with no loss, or with the same relative loss in all, and also the maintaining of all the simple waves that make up the complex wave in the same phase relation as in the original wave. This is also an impossibility, because there are

certain electrical properties, possessed to a greater or less extent by every circuit, that tend to alter the form of the complex wave either by reducing the relative amplitude of the waves corresponding to the higher overtones or by displacing, in phase, the waves corresponding to the overtones with respect to each other or with respect to that of the fundamental tone. These various properties and the effects they produce on the form or amplitude of the waves may be understood only after some knowledge is obtained of the theory of alternating currents.

DIAGRAMMATIC REPRESENTATION OF ELECTRICAL WAVES

6. Analysis of Curves.—The successive values of the current or of the electromotive force may be represented by means of curves in the same manner as already used in representing the form of sound waves. In Fig. 2, the horizontal line AE may be considered as representing time, while the vertical lines fe, bB, dD, and $f'e'$ represent the instantaneous values of the current or electromotive force at corresponding particular moments. This may perhaps be made clearer by first assuming that the curve $ABCDE$ represents the values through which the current passes in the course of a complete cycle. The distance AE along the horizontal line will then represent the time taken for the current to pass through a complete cycle, and the distance Af will represent the time in which the current has risen from zero to a value represented by the line ef. Ab will represent the time taken for the current to pass through a quarter cycle, and the line Bb will represent the maximum positive value of the current. During the time represented by the distance between b and C, the current decreases, its value at any time being represented by the perpendicular distance or length of the ordinate between the horizontal line AE and the curve. At the point C, which corresponds to the end of the first half cycle, the current passes through zero and begins to increase in a negative direction; that is, it begins to flow and increase in strength in the opposite direction in

the circuit. The distance $A\,d$ represents the time of three-quarters of a cycle, at which time the current has reached its maximum negative value, and after passing through which it gradually decreases to zero at the point E, which marks the end of the first complete cycle.

7. If the current is generated by a diaphragm vibrating with a simple harmonic motion in the field of an electromagnet, its curve will also be a representation of a simple harmonic motion, and may be considered as being generated by the revolution of the line $O\,p'$, Fig. 2, around the point O. The distances measured along the horizontal line from the point A may therefore, as in the case of simple harmonic motion, represent the portion of the cycle, in degrees, through which the wave has passed at any instant. Thus, the distance $A\,f$ will represent the angular distance through which the line $O\,p'$ revolved in passing from the position $O\,A'$ to the position $O\,p'$, which, as may be seen by mere inspection, is approximately 45°. The distance $A\,b$ corresponds to the rotation of the line $O\,p'$ through an angle of 90°, at which time the value of the current is a maximum. In like manner, $A\,C$ may represent a rotation of 180°, $A\,D$ 270°, and $A\,E$ 360°, or a complete cycle. The curve shown in Fig. 2 may, instead of representing current, represent the successive values of the electromotive force producing the current, the value of the electromotive force at any time being represented by the ordinate of the corresponding point on the curve in exactly the same manner as when the curve was considered to represent the successive values of the current.

8. The length of the line $O\,p'$, Fig. 2, is the same as the lines $B\,b$ and $D\,d$, which represent, respectively, the maximum and minimum values of the current or electromotive force. It is therefore often convenient, in reasoning or calculating about alternating-current phenomena, to represent the maximum value of the current or electromotive force by such a line as $O\,p'$, and the phase of the current or electromotive force at any instant by the angle that the line makes with some line of reference, such as the horizontal

line OA'. Thus, the left-hand portion of the figure included within the circle may be used to convey the same meaning as the right-hand portion of the same figure, including the sine curve $ABCDE$. The maximum value of the current is represented by the radius of the circle, and the instantaneous value at any time, or at any portion of the cycle, may be found by dropping an ordinate from the point p' on the circumference to the horizontal diameter.

If the curve in this figure represents an alternating current or electromotive force, then, when the alternating current or electromotive force starts at A, passes through all the positive values (that is, along the curve $AeBC$ above the axis), returns to the axis at C, passes through all the negative values (that is, along the curve CDE below the axis), and returns to the axis at E, it is said to have made one complete cycle.

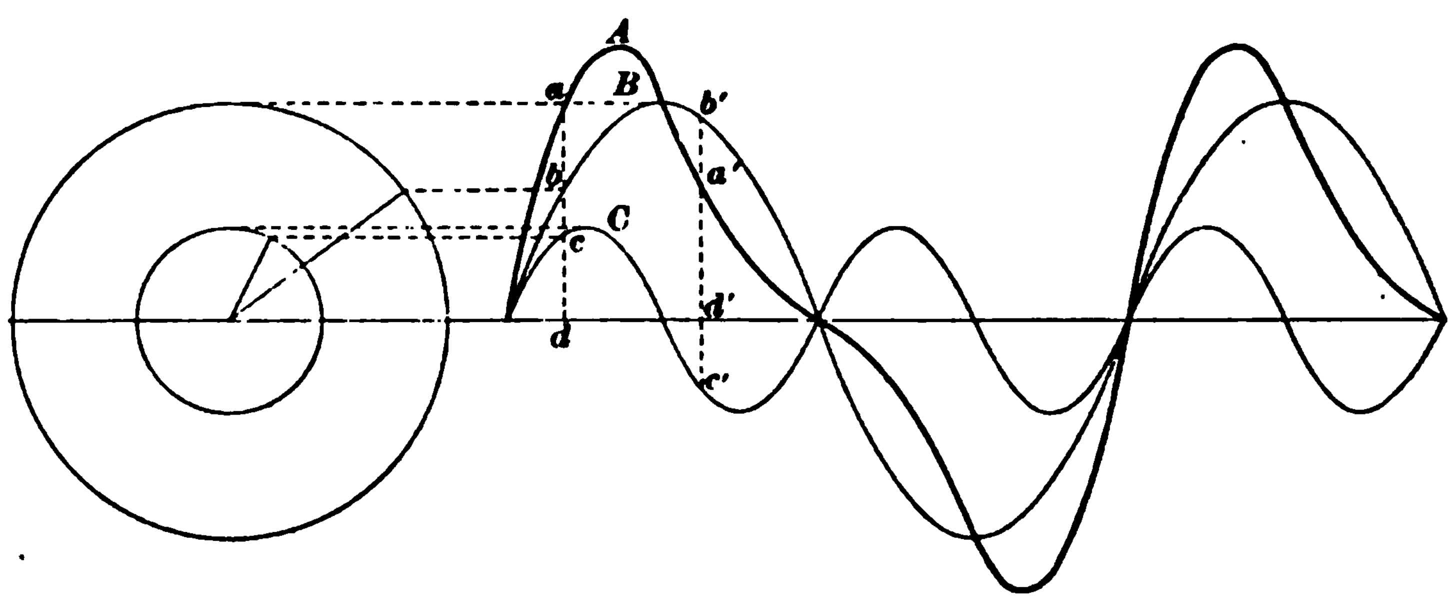


FIG. 3

9. Complex Alternating-Current Wave.—Fig. 3, which was used to illustrate the production of a complex sound wave A by combining two simple sound waves B and C, may be also used to represent the formation of a complex current wave from two simple sine waves. The maximum values of the currents represented by curves B and C will be represented by the radii of the large and small circles, respectively. The curve A, being a complex instead of a simple harmonic wave, cannot be represented by a radius revolving around the center of a circle, as in the cases already described.

RESISTANCE

10. Resistance is that property of a circuit that tends to obstruct the passage of a current. The relation between the values of a continuous current, a continuous electromotive force, and resistance is defined by Ohm's law, which may be stated as follows: The current, expressed in amperes, is equal to the electromotive force, expressed in volts, divided by the resistance of the circuit, expressed in ohms. The effect of resistance, when not modified by any other properties of the circuit, such, for instance, as self-induction or capacity, is the same for alternating currents as for direct currents. It causes neither a lag nor a lead in the current wave, nor does it alter the form of the wave, its only effect being to diminish its amplitude. This diminution in amplitude is, under these circumstances, in exact accordance with Ohm's law, the effective or the maximum values of the current for any cycle varying directly with the effective or maximum electromotive force.

INDUCTANCE

11. If two wires lie side by side, an increase in the current in one will induce an electromotive force in the other tending to produce a current in the opposite direction to the inducing current. On the other hand, a decrease in the current flowing in one will induce in the other an electromotive force that tends to produce a current in the same direction as the inducing current. The convolutions, or turns, of a coil form practically parallel wires and each turn acts on all other turns in the same manner as one parallel wire acts on another, but producing very much greater results. The number of turns may be readily increased by winding more wire on a coil; but in order to do this where a limited amount of space is available, it is frequently necessary to wind with a smaller wire. The number of lines of force set up through a coil depends, not only on the strength of the current and number of turns, but also on the character of the magnetic substance in and around the coil. A coil having

no iron in its core will have a very much lower inductance than a coil that has, for the reason that the number of lines of force set up by a given magnetizing force is much greater in iron than in air. We may say, therefore, that a large amount of iron in the core of a coil serves to greatly increase the inductance; and where the return path for the lines of force is also made of iron, the inductance is still further increased, because the entire magnetic circuit is made of iron. This is the reason why electromagnetic devices, such as drops and relays, that are bridged across telephone circuits and impedance, or retardation, coils, are made with as complete magnetic circuits as possible. The number of turns in such apparatus is usually large. By winding a coil that is completely surrounded with iron with a large number of turns of as large wire as it is practical to use, it is possible to obtain a coil of very high impedance to high-frequency currents, but of comparatively little resistance to a steady continuous current, and an impedance not much greater than the resistance to a very low-frequency alternating current.

12. Inductance of Telephone Apparatus.—An idea of the inductance of telephone apparatus may be obtained from the following values: The secondary winding (256.2 ohms) of an induction coil for use with a Blake transmitter had an inductance of .035 henry for a current of .0824 ampere; an 80.3-ohm double-pole Stromberg-Carlson receiver, .33 henry for a current of .0124 ampere; a 125.3-ohm single-pole Best Telephone Company receiver, .15 henry for a current of .0162 ampere; an ordinary (old-style) 133.8-ohm switchboard drop, .5 henry for a current of .074 ampere (these four values are for a frequency of 133 periods per second); a 101-ohm polarized bell, 2.82 henry for current of .033 ampere and frequency of 48.4 periods per second; a 353.8-ohm armature of a magneto-generator, 4.27 henrys for a current of .024 ampere and a frequency of 48.4 periods per second; a 75-ohm watch-case receiver, about .01 henry; one 200-ohm winding of a repeating coil, 3.5 henrys; a 1,000-ohm (bridging) polarized bell at 400 periods per second, 2 to 4 henrys,

at 16 periods, 10 henrys; a Bell double-pole receiver at 400 periods per second, .39 henry, at 1,000 periods, .27 henry, at 1,500 periods, .22 henry; a 550-ohm switchboard drop (iron-clad) at 400 periods per second, about 5 henrys. Where known, the current and frequency are given because the inductance of coils containing iron will vary somewhat with the current and the frequency. Measurements show that the value of the inductance depends somewhat on the frequency; generally, it seems to decrease as the frequency increases, but no explanation can be given, except that it may be due to the fact that as the frequency increases the less deeply does the magnetism penetrate into the interior of the iron core. This is sometimes said to be due to the viscous hysteresis of the iron. Iron wire larger than No. 25 B. W. G. should never be used for the cores of repeating and induction coils, because so-called *eddy currents* are readily induced in a solid iron core; these currents are useless and also represent a loss of energy, thereby causing a loss in the efficiency and in the good talking quality of the instrument. It is customary to consider the inductance of a given coil as having almost a constant value.

13. Electromotive Force of Self-Induction.—The electromotive force brought into existence by self-induction is called the **electromotive force of self-induction**, or the **pressure of self-induction**, in order to distinguish it from the impressed electromotive force, or pressure, which, as its name indicates, is that impressed on the circuit by the generator that is causing the current to flow. The active pressure is the resultant of the pressure of self-induction and the impressed pressure.

14. Effects of Inductance on Alternating Currents.—It is evident, since inductance tends to oppose any change being made in a current flowing in a circuit, that the effect will be to make any change in current strength occur slightly later than it would otherwise do. In a circuit containing only resistance, without inductance or capacity, an alternating current will be in exact phase with the electromotive

force impressed on the circuit; that is, the maximum value of the current will occur at the same time as the maximum value of the electromotive force, and the corresponding zero and intermediate values of current and electromotive force will also occur at the same times. When inductance is introduced into the circuit, however, it causes the changes in current to occur somewhat later than the changes in the electromotive force, or, as it is customary to express it, to lag in phase behind the electromotive force.

15. Phase Relations.—The electromotive force of self-induction is proportional at all times to the rate of change of the current flowing in the circuit, and not proportional to the current itself. Therefore, the electromotive force of self-induction is a maximum when the current is passing through zero, because at that time the current is changing faster than at any other time. Likewise, the electromotive force of self-induction is zero when the current is maximum; for when the current is maximum, the rate of

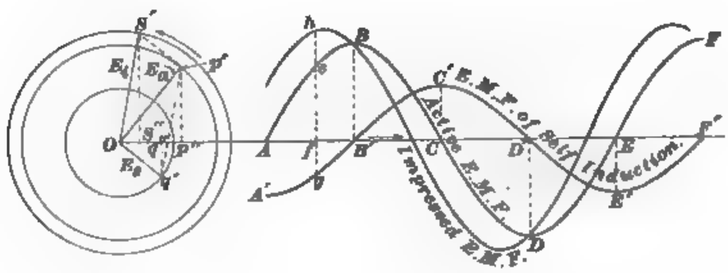


FIG. 4

change of the current is zero. These facts may be more readily grasped by again referring to Fig. 2. If the curve is taken as representing the instantaneous values of the current, it will be seen that at the zero points *A*, *C*, and *E*, the current is changing most rapidly, for the curve is steepest, and the electromotive force of self-induction will be greatest, at these points. At the maximum points *B* and *D*, the rate of change of current is zero, and therefore the electromotive force of self-induction will be zero.

In Fig. 4, the curve $A\,B\,C\,D\,E$ represents the same curve as that shown in Fig. 2, and in this case it is taken to represent the successive values of the active electromotive force; that is, of the electromotive force that is actually driving the current through the circuit, and which is therefore in phase with the current. The curve $A'\,B'\,C'\,D'\,E'\,F'$ represents the electromotive force of self-induction, it being so drawn that its maximum values A', C', and E' occur at the same time as the zero values A, C, and E of the active electromotive force. In like manner, the zero points B', D', and F' occur at the same time as the maximum values B, D, and F of the active electromotive force. A little consideration shows that the electromotive force of self-induction lags behind the active electromotive force by an amount equal to the distance $A\,B'$ or, if expressed in angular measure, by 90°, or a quarter of a cycle. It is always true that the electromotive force of self-induction lags 90° behind the active electromotive force, and therefore 90° behind the active current, which is always in phase with the active electromotive force.

16. Impressed Electromotive-Force Curve.—The curve $A\,B\,C\,D\,E$ in Fig. 4 may, as we have already seen, be considered as generated by the revolution of the line $O\,p'$ about the point O. The length of the line $O\,p'$ is made equal to the maximum value of the active electromotive force, and this line is, for the purpose of clearness, designated E_a. The line $O\,q'$ represents the electromotive force of self-induction, and is therefore termed E_s. Its length is made equal to the maximum value of the electromotive force of self-induction; and as this has been shown to lag in phase behind the active electromotive force by an amount equal to 90°, the line E_s is drawn at right angles to the line E_a and behind it. If the lines E_s and E_a are revolved around O, keeping them at all times the same number of degrees apart, the line E_s will generate the curve $A'\,B'\,C'\,D'\,E'\,F'$, representing the electromotive force of self-induction, while the line E_a is generating the curve $A\,B\,C\,D\,E\,F$, representing the active electromotive force. The curve of the impressed electromotive

force may be found by taking the algebraic differences of the instantaneous values of the active electromotive force and of the electromotive force of self-induction. Thus, the point h on the curve of the impressed electromotive force may be found by making the length of the ordinate fh equal to the sum of the ordinates fe and fg, the sum being taken because the ordinate fe is positive, while the ordinate fg is negative; and to subtract the latter from the former, we have only to change its sign and add, according to the well-known rule of subtraction in algebra. That is, $fh = fe - (-fg) = fe + fg$.

17. Angle of Lag.—The curve representing the impressed electromotive force may be worked out, point by point, by thus taking the algebraic differences between the ordinates of the curve of active electromotive force and that of the electromotive force of self-induction. A better way, however, is by completing the triangle of which the lines E_a and E_s form two sides, as shown at the left hand of Fig. 4. Remembering that the active electromotive force is the resultant of the impressed electromotive force and the electromotive force of self-induction, we have only to draw the line E_i, which represents the impressed electromotive force, making it parallel and equal to the line $p'q'$, so that the line E_a represents the resultant in the ordinary triangle of forces, of which $p'q'$ and Oq' are the sides. The line E_i, which is equal and parallel to $p'q'$, will then represent, by its length, the maximum value of the impressed electromotive force; and by its angular position, the phase relation with respect to the active electromotive force and the electromotive force of self-induction. This line, if revolved around the point O, will generate the curve representing the impressed electromotive force, as shown. The actual current flowing in the line will be in phase with the active electromotive force E_a, and the angle between the line E_i and the line E_a will therefore represent the lag in phase of the current behind the impressed electromotive force. This angle is termed the **angle of lag.**

The effect of the self-induction is to retard the rise and fall of the current so that it attains its maximum later than the maximum of the alternating pressure that sets it up; and it also increases the apparent resistance to the flow of the alternating current in the circuit. Thus, if the curve *M*, Fig. 5, is taken to represent the alternating current that flows in a circuit supposed to contain no self-induction, then *N*

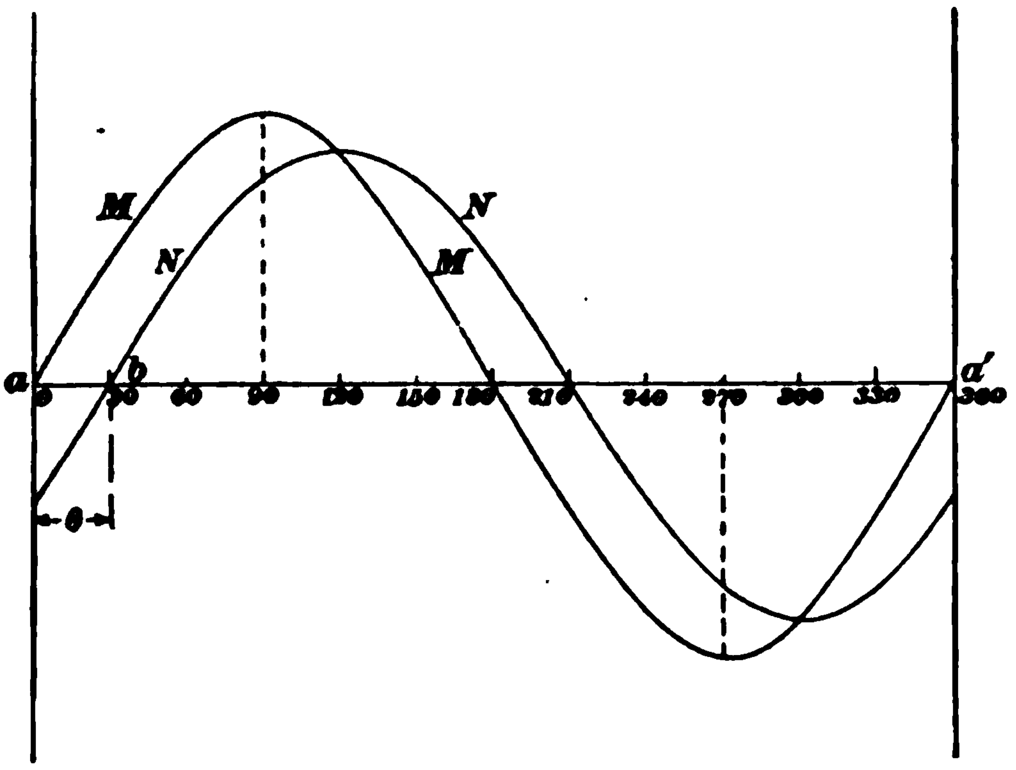


FIG. 5

can be taken to represent the current that flows when there is self-induction. *N* is retarded with respect to *M* and reaches a smaller maximum value. In this figure, the distance θ (pronounced thê'ta) from *a* to *b*, expressed in degrees, is called the angle of lag θ. For *a a'* represents one complete period, that is, 360°; consequently, each $\frac{1}{360}$ part of the distance *a a'* is equivalent to 1°. In this figure, the curve *N* lags 30° behind the curve *M*.

ELECTROSTATIC CAPACITY

18. Condensers.—All bodies have the power of accumulating charges of electricity on their surfaces, and two such charges mutually attract or repel each other according to whether they are of the same or opposite sign. The amount of charge that a given conductor will take is greatly increased by the proximity of another conductor to it. Two conducting bodies placed close together and insulated

from each other form what is called a condenser. For commercial work, condensers are usually made of a large number of sheets of tin-foil, laid one on the other, each sheet being insulated from those adjacent to it by sheets of paper impregnated with insulating compound. The alternate layers of tin-foil are connected together at one side and

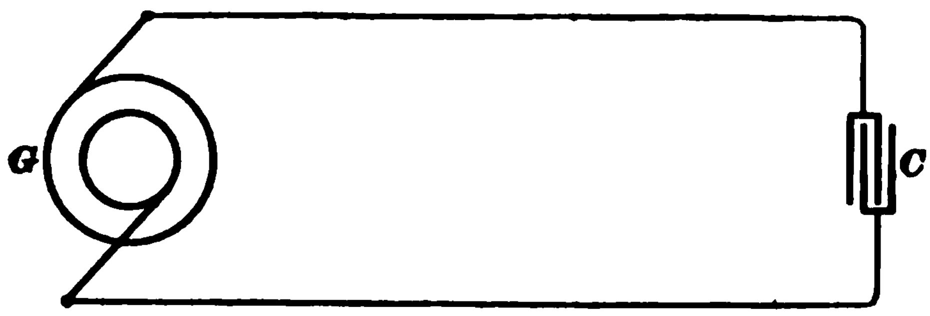


FIG. 6

to a point forming one terminal of the condenser, while the remaining plates are similarly joined to a point forming the other terminal of the condenser. The result of this construction is to give two conducting surfaces of large area separated from each other by a thin insulating medium.

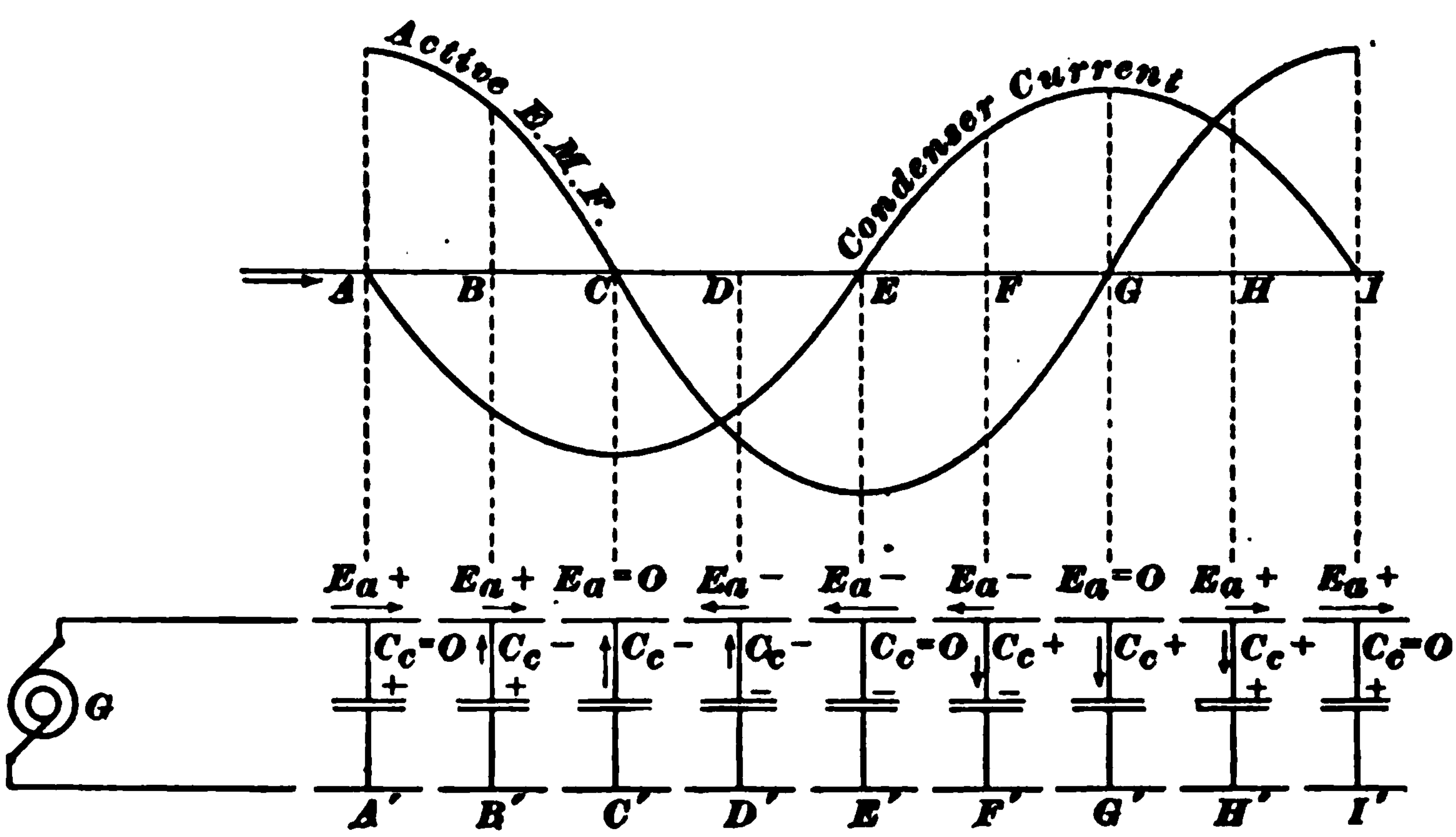


FIG. 7

19. The Effect of Capacity on Alternating Currents.—If a condenser C is placed in the circuit of a generator G of alternating currents, as shown in Fig. 6, its terminals will be subjected to electromotive forces varying rapidly from a maximum in one direction to a maximum in the other direction. As the condenser receives a charge

from the line, or discharges itself back into the line, currents will flow into or out of it, according to whether the pressure at its terminals is increasing or decreasing. The phase relation between the current flowing into or out of the condenser and the electromotive force of the line is somewhat difficult to understand. For the purpose of illustrating it, reference will be made to Fig. 7, in which G is a source of alternating current, the wave form of which is that of a sine curve. The two plates of a condenser are shown connected across the two sides of the line at A', and in order to illustrate the conditions throughout a complete cycle of the current, the same condenser is shown at successive points, such as B', C', D', E', etc., these points being under the corresponding points A, B, C, D, E, etc., on the horizontal line of the current and electromotive force curves directly above. One of the curves, as indicated, represents the rise and fall of the active electromotive force, while the other represents the corresponding values of the condenser current.

It should be remembered that the amount of current flowing into or out of the condenser depends on the rate of change of the electromotive force at its terminals; but the amount of the charge in the condenser depends on the instantaneous value of the electromotive force and not on its rate of change. Evidently, as long as the electromotive force at the condenser terminals does not change, no current will flow into or out of the condenser, but if the electromotive force across the condenser terminals is gradually raised, current will flow into the condenser; and if gradually lowered, current will flow out of the condenser. The faster these changes in the potential across the condenser terminals take place, the greater will be the instantaneous value of the current flowing into or out of the condenser.

20. Phase Relations.—Consider now the conditions at the instant represented by A on the curve diagram and at A' in the lower part of the figure. At this instant, E_a, the active electromotive force, is maximum and positive (all currents or electromotive forces above the horizontal line

being considered positive and all those below it negative). The upper plate of the condenser is positive and at the same potential as the upper conductor of the circuit. At this instant, the electromotive force is undergoing no change, it being just at the turning point between the increase and the decrease; consequently, the condenser is fully charged, but no current is flowing into or out of it. The current flowing into the line, being in phase with the active electromotive force, is at this instant maximum, and its direction is indicated by the horizontal arrow above the point A'. It is evident, therefore, that while the active electromotive force is maximum, the condenser current is zero, and therefore the curve representing the condenser current passes through the horizontal axis at the point A. At the time represented by the point B on the horizontal axis, E_a is smaller than before, but still positive. The top condenser plate is therefore still positive, but at a lower potential than at the point A'. From this, it follows that the condenser cannot now hold all its previous charge, and therefore current must flow out of it and into the line, as indicated by the small vertical arrow above the point B'. This current is in an opposite direction from that which would flow from the generator G through the condenser path were the condenser short-circuited, and is therefore of an opposite sign to that of the line current. Inasmuch as the line current is still positive and in a direction indicated by the small horizontal arrow above B', the condenser current must be negative; i. e., flowing out of the top plate, as indicated by the arrow above point B', and therefore the point on the condenser-current curve at that instant is below the horizontal axis.

21. At the instant represented by the points C and C', the active electromotive force is zero and is undergoing its maximum rate of change. The top condenser plate is neutral; i. e., it has no charge, but is rapidly decreasing toward a negative value. Therefore, since the potential of the top plate is decreasing, current must be flowing out of it, as indicated by the vertical arrow, and as E_a is changing at a

maximum rate, the condenser current at this point is a maximum. At the points represented by D and D', the active electromotive force has changed from a positive to a negative direction, as is indicated by the small horizontal arrow. This same electromotive force may now be said to be increasing in a negative direction, or, what is the same thing, decreasing in a positive direction. The subject will be made somewhat clearer by considering it in the latter light, that is, by considering the change of the active electromotive force from the positive maximum to the negative maximum to be one steady decrease, and likewise the change from the negative maximum to the positive maximum to be one steady increase. The active electromotive force at D is then still decreasing. The direction of the current in the line is indicated by the horizontal arrow above the point D'. The potential of the top condenser plate is now negative, and therefore lower than the potential was at the time represented by the point C. Current is therefore still flowing out of the condenser, although the value of the condenser current is not as great as at the preceding point. It will be noticed that the points on the two curves are on the same side of the horizontal axis, signifying that the line current that is in phase with the active electromotive force and the condenser current are in the same direction. At the point E, the active electromotive force reaches its maximum negative value and ceases to decrease. Current in the line is maximum and the upper plate has its maximum negative charge, while the condenser current is zero, because the active electromotive force is at this instant undergoing no change. So far, the condenser current has been entirely in a negative direction, and by reference to the corresponding active electromotive force curve, it will be seen that the active electromotive force has during this time been steadily decreasing. After the time represented by the point E, the active electromotive force begins to increase; and until the time represented by the point I is reached, this increase continues. During this time, the potential of the top condenser plate is gradually raised, allowing the condenser to receive more and more charge,

the charge changing from a negative maximum value at E to zero at G, then to a maximum positive value at I, and therefore causing a continuous flow of current into the condenser, this current reaching a maximum value at the time represented by the point G when the active electromotive force is undergoing its maximum rate of change.

22. Angle of Lead.—Reference to the two curves in Fig. 7 will show that the condenser current is zero when the active electromotive force, and therefore the active current, is maximum, and that the condenser current is maximum when the active current is zero. This indicates a difference in phase between the condenser current and the active current of 90°, and a further inspection of the curve will show that the condenser current is in advance of the active electromotive force by that amount. Thus, at the point A, the condenser current is zero and is decreasing; at the point C, which occurs later than the point A, the active electromotive force is zero and is decreasing. The condenser current therefore reaches this zero point while decreasing, a quarter of a cycle before the active electromotive force or active current. A comparison of any other similar points on the two curves will show that the condenser current always reaches a certain value just 90° in advance of the active electromotive force or current. It is, therefore, said that the condenser current leads the active current by an amount equal to 90°. The electromotive force that is in phase with the condenser current is called the condenser electromotive force, and is, of course, 90° in advance of the active electromotive force.

23. It must be remembered that the active electromotive force is not the same as the impressed electromotive force, which is that impressed on the line by the generator G. The active electromotive force is the resultant of the impressed electromotive force and the condenser electromotive force. This relation is shown in Fig. 8, where the curve of active electromotive force is generated by the revolution of the line E_a about the center point O, and the condenser electromotive force is generated by the revolution of

the line E_c about the point O in unison with the line E_a. The line E_a represents the maximum value of the active electromotive force, and the line E_c the maximum value of the condenser electromotive force, the latter being drawn at right angles to the former, since there is a phase difference of 90° between them, and in advance of E_a, since E_c is ahead of it in phase. The curve of the impressed electromotive force is found by making the ordinates of the points on it equal to the algebraic difference of the corresponding ordinates of the active electromotive force and the condenser electromotive force, in exactly the same manner as the curve of impressed electromotive force was determined in Fig. 4.

The position of the line E_i generating the curve of the impressed electromotive force may be found by completing

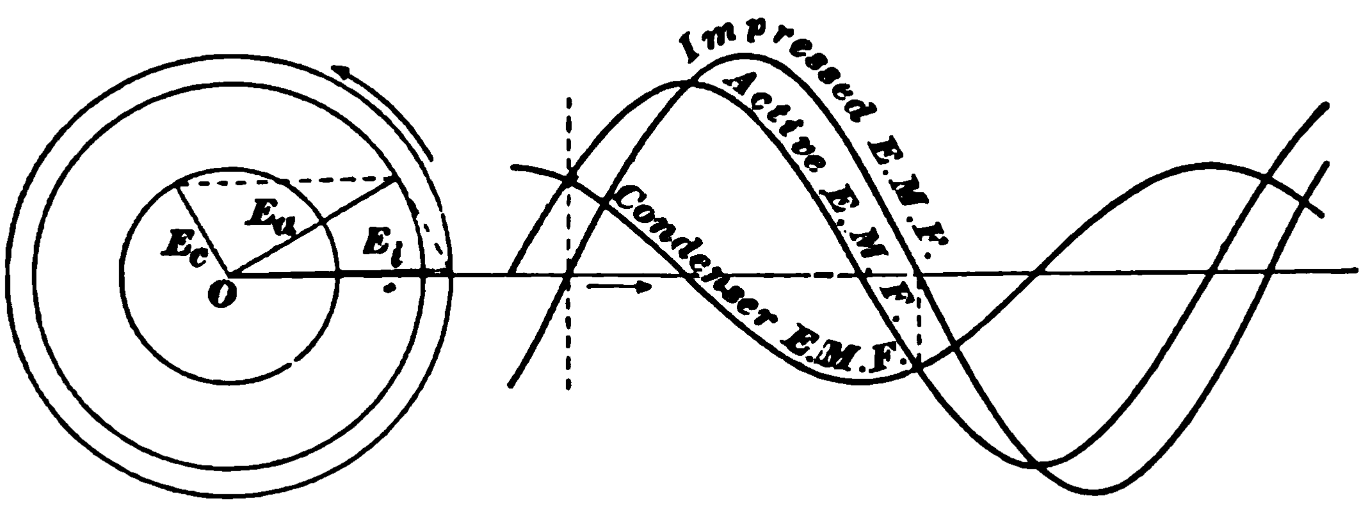


FIG. 9

the triangle of which E_c forms one side and E_a the other side. The length of the line E_i, which is equal and parallel to the dotted line joining the ends of E_c and E_a, and its position show the maximum value of the impressed electromotive force, and also its phase relation with respect to the active electromotive force. If the condenser were not present, E_c would be equal to zero and the impressed electromotive force would be in phase with and equal to the active electromotive force. When the condenser is present, however, the effect of its electromotive force is to bring the active electromotive force ahead of the impressed electromotive force in phase. This difference in phase is represented by the angle between the line E_a and the line E_i, and is called the **angle of lead, or angle of advance.**

DISTORTION OF TELEPHONIC WAVES

24. Effect of Resistance.—The effect of resistance when not modified by self-induction or capacity is the same on alternating or rapidly fluctuating currents as it is on direct currents. It serves merely to reduce the amplitude of the wave without modifying its form. The electromotive force necessary to overcome resistance produces a current that serves only to heat the conductor through which it flows. This effect causes no lag or lead in the current wave behind the impressed electromotive force, acts on currents of all frequencies in exactly the same manner, and does not therefore serve to impair clearness of articulation. Telephonic communication can be successfully carried on through a circuit having a resistance as high as 3 megohms or 3,000,000 ohms, if the circuit has no self-induction or electrostatic capacity, and as this resistance is many times higher than that over which it is ever required to commercially transmit speech, it follows that the resistance alone of a circuit is not in itself a serious obstacle to telephonic transmission.

25. Effect of Inductance.—If resistance alone is present in a circuit the current will keep in phase with the impressed electromotive force, and will suffer only diminution in amplitude in direct accordance with Ohm's law. When inductance is added, however, the electromotive force set up by it causes the current to lag behind, and also serves to further reduce the amplitude of the current; for the impressed electromotive force has not only to overcome the ohmic resistance of the circuit, but also the electromotive force of inductance.

If telephone currents followed such a simple law as simple harmonic motion, the lag in the current behind the impressed electromotive force would not be such a serious matter, and would serve only to diminish the amplitude of the waves without destroying the form. The lag in the current would amount to merely shifting the entire current curve so that its various values would occur slightly later than the corresponding

values of the impressed electromotive force, but this shifting would not produce any changes in the actual form of the wave. Telephone currents do not, however, follow such a simple law, but are made up of a number of simple waves having different amplitudes and different frequencies. Unfortunately, inductance causes a greater diminution in the amplitudes of the waves of high frequencies than in those of low frequencies, and also a much greater angle of lag. Therefore, vibrations of low frequency meet with less effective resistance than those of high frequency. The total opposition offered to an alternating current by a circuit having inductance or capacity, or both, in addition to the so-called simple ohmic resistance, is called its *impedance*. The impedance of a circuit possessing resistance and inductance for a simple sine-wave current is expressed by the following formula:

$$\text{Impedance} = \sqrt{R^2 + (2\pi n L)^2} \qquad (1)$$

in which R = simple resistance of the circuit, in ohms;
π = 3.1416;
n = number of complete periods per second, or the frequency;
L = coefficient of self-induction, now called simply inductance, expressed in henrys.

From the fact that the current I in an alternating-current circuit is equal to the electromotive force E divided by the impedance, i. e.,

$$I = \frac{E}{\sqrt{R^2 + (2\pi n L)^2}} \qquad (2)$$

it can be easily shown that a given circuit possessing inductance reduces currents of high frequency more than those of low frequency; for the larger the value of n in the above expression, the smaller will be the value of the current I.

Thus, in a wave that is the resultant of waves of several different frequencies, the amplitude of the high-frequency waves will be reduced to a greater extent than those of low frequency; that is, in a current wave caused by a sound, the higher the overtones the more they are reduced in amplitude.

Furthermore, high-frequency currents lag more than those of low frequency. This can be seen from the formula:

$$\tan\theta = \frac{2\pi n L}{R} \qquad (3)$$

which expresses for a simple sine curve the relation between the tangent of the angle of lag θ and the frequency, inductance, and resistance of the circuit. The latter two formulas show that the currents, due to the higher overtones in a complex wave, are reduced more in amplitude and are displaced more in their relative position to the lower overtones and the fundamental than are the currents due to the lower overtones. These two results of inductance produce very serious deformations of current waves, and, when present to too great an extent, render the transmission of speech too indistinct to be understood at all.

EXAMPLE.—What is the impedance of a coil, whose resistance is 130 ohms and inductance .5 henry, to an alternating current whose frequency is 300 periods per second?

SOLUTION.—According to the formula for the impedance of a circuit possessing only resistance and inductance, which is, impedance $= \sqrt{R^2 + (2\pi n L)^2}$, we get

$$\sqrt{(130)^2 + (2 \times 3.1416 \times 300 \times .5)^2} = 951.4 \text{ ohms. Ans.}$$

26. Effect of Capacity.—A condenser placed across a telephone circuit produces a displacement in phase in the opposite direction from that produced by inductance. The effects produced are similar to those produced by inductance, namely, a distortion of the wave and a reduction of the amplitude. The distortion of the wave is caused by the unequal effect of the capacity on the various component waves in the voice currents. The waves corresponding to the higher overtones are given a smaller lead ahead of their impressed electromotive forces than those corresponding to the lower tones, and are reduced in amplitude to a less extent. Contrary to the case of inductance, capacity in a circuit possessing only resistance and capacity serves to give the current waves of the higher overtones a smaller phase

displacement than those of the lower, and also to give them a smaller proportional reduction in amplitude.

The impedance of a circuit possessing only resistance and capacity is expressed, for a simple sine alternating current having a frequency of n, by the formula:

$$\text{Impedance} = \sqrt{R^2 + \left(\frac{1}{2\pi n C}\right)^2} \qquad (1)$$

in which C is the electrostatic capacity, in farads, the other letters having the same meaning as in preceding formulas. The tangent of the angle of lead is given by the expression:

$$\tan\theta = \frac{1}{2\pi n C R} \qquad (2)$$

These two formulas show that the higher overtones in a complex wave, such as would be caused by a vowel sound, for instance, are reduced less in amplitude and are displaced less than are the lower overtones; for evidently the current that is given by the formula,

$$I = \frac{E}{\sqrt{R^2 + \left(\frac{1}{2\pi n C}\right)^2}} \qquad (3)$$

becomes larger, and the tangent of the angle of lead, $\left(\frac{1}{2\pi n C R}\right)$, becomes smaller the larger n becomes. These two effects produce, as in self-induction, but in the opposite direction, very serious deformations in the current waves; and are, therefore, very detrimental to good transmission of articulate speech.

The above formulas for capacity apply to circuits in which the condensers are in series with the line and other apparatus. Distributed capacity, which cannot be treated in this manner, produces effects that will be considered later.

Condensers are only used in telephone circuits where it is necessary that they should perform some particular function, and they introduce what is called **local capacity** into the

circuit, but this is usually so arranged as not to be detrimental to telephone transmission.

EXAMPLE.—What is the impedance of a circuit containing a non-inductive resistance of 100 ohms and a condenser of 2 microfarads capacity to an alternating current whose frequency is 300 periods per second?

SOLUTION.—First, reduce 2 microfarads to their equivalent value in farads. One farad = 1,000,000 microfarads, hence 2 microfarads = $\frac{2}{1000000}$ farad. Substituting, in the formula, impedance $= \sqrt{R^2 + \left(\frac{1}{2\pi n C}\right)^2}$ gives

$$\sqrt{(100)^2 + \left(\frac{1,000,000}{2 \times 3.1416 \times 300 \times 2}\right)^2} = 283 \text{ ohms. Ans.}$$

27. Combined Effect of Resistance, Inductance, and Capacity.—For any given frequency of an alternating current, the effect of inductance of the circuit may be neutralized by the application of a capacity of the proper value. That this is true may be seen by comparing Figs. 4 and 8. In Fig. 4, the inductance present has caused the active electromotive force E_a to lag about 30° behind the impressed electromotive force E_i. In Fig. 8, the electromotive force due to capacity has caused the active electromotive force to advance in phase ahead of the impressed electromotive force by about an equal amount. By properly proportioning the inductance and the capacity of a circuit, the electromotive force of inductance may be made to neutralize the electromotive force due to the condenser, thus allowing only the impressed electromotive force to be active in driving current through the circuit. In this case, the impressed electromotive force and the active electromotive force are the same, and the current is in phase with the impressed electromotive force, as it would be were no inductance or capacity present.

This can also be shown by the formula for the impedance of a circuit possessing simple resistance, inductance, and capacity. For an alternating sine curve, this impedance is expressed as follows:

$$\text{Impedance} = \sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n C}\right)^2} \qquad (1)$$

and the tangent of the angle of lag or lead, as the case may be, as follows:

$$\tan \theta = \left(\frac{2\pi n L}{R} - \frac{1}{2\pi n C R}\right) \qquad (2)$$

These formulas assume that the resistance, inductance, and capacity are all in series with the line and apparatus. From these two formulas, it is quite evident that the impedance becomes equal to the simple resistance, and there is no angle of lag or lead when $\left(2\pi n L - \frac{1}{2\pi n C}\right) = O$. For a given circuit having a definite inductance L and electrostatic capacity C, it is quite plain that this expression can be exactly equal to zero for only one particular value of the frequency n.

In a circuit possessing resistance, inductance, and capacity, the current may be found by the formula:

$$I = \frac{E}{\sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n C}\right)^2}} \qquad (3)$$

This is based on the assumption that the current wave is a sine curve.

In overhead lines, and especially in cables, the distributed capacity effects are much more serious than those due to inductance, but in the apparatus the effects of inductance are the greater.

While it is desirable to have a reasonably loud sound given by the receiver, clearness is also very important, perhaps more so than loudness, for the faintest speech is readily understood if it is only clear. A current wave corresponding, for instance, to a consonant sound, is very complex, and to transmit this clearly requires the preservation of all the overtones in their exact original relations to each other and to the fundamental, both in amplitude and phase.

The inductance of a coil can be neutralized by a condenser having a capacity such that $2\pi n L = \frac{1}{2\pi n C}$. For a given inductance and a given frequency, the condenser must have

a certain capacity; for any other capacity, the neutralization will not be perfect. If the frequency is changed, the capacity of the condenser must be changed to perfectly neutralize the same inductance. The neutralization of distributed capacity by inductance coils distributed along the line for all frequencies of the voice currents seems to contradict the above statement, which is true nevertheless. Pupin has proved that if distributed capacity is neutralized by inductance coils distributed properly along the line for a frequency of about 600, which is nearly the highest frequency occurring in ordinary conversation, that the neutralization is sufficiently good for all lower frequencies to greatly improve the transmission over long line and cable circuits.

EXAMPLE.—A condenser of what capacity, in microfarads, must be connected in series with a telephone bell having a resistance of 1,000 ohms and an inductance of 8 henrys in order to give a minimum impedance to an alternating current having a frequency of 20 cycles per second?

SOLUTION.—The least impedance such a circuit can possess is the resistance of the coil; namely, 1,000 ohms. To get such an impedance, the capacity and inductance must neutralize each other; in other words, $2\pi n L - \frac{1}{2\pi n C}$ must equal zero. If $2\pi n L - \frac{1}{2\pi n C} = 0$,

$$C = \frac{1}{4\pi^2 n^2 L} = \frac{1}{4 \times (3.1416)^2 \times (20)^2 \times 8} = .00000792 \text{ farad}$$

or 7.92 microfarads. Ans.

DIRECT AND ALTERNATING CURRENTS IN PORTIONS OF THE SAME CIRCUIT

28. As condensers, inductance coils, and non-inductive resistances are used extensively in telephone systems, their action on direct and alternating currents should be understood. It might be well to say that a coil wound, in one direction only, around an iron core possesses inductance and hence acts as an inductive resistance, whether the iron core is part of a relay or any other electromagnetic mechanism, or is simply used to increase the inductance of the coil. Furthermore, the total opposition called *impedance*, that an inductance coil offers to an alternating, or rapidly flucuating,

current increases with the resistance, number of turns, and frequency of alternation. Where the frequency is very high and the resistance very low, the resistance may be an entirely negligible part of its impedance. On the other hand, the steady direct current that will flow through the inductance coil will depend on its resistance and not on its inductance.

A condenser, on account of the very high resistance of its insulating sheets, will not allow a direct current of appreciable strength to flow through it, but is said to allow an alternating, or rapidly fluctuating, current, such as is produced when telephoning, to flow through it. This does not mean that any current actually flows through the insulating sheets of the condenser, but rather that the plates of the condenser are charged and discharged; that is, the charges on the plates are reversed in polarity every time the potential is reversed at the condenser's terminals and the quantity of electricity on the plates changes every time the potential changes in value. Whenever there is a change in the amount or polarity of the charge on the condenser plates, some electricity must flow into one side and out of the other side of the condenser and through the circuit, and just as much electricity must flow into one side as flows out of the other; that is, the positive charge on one side is always equal to the negative charge on the other side of the condenser. Moreover, the opposition that a condenser offers to the flow of an alternating, or rapidly fluctuating, current decreases as its capacity and the frequency increase. In telephone circuits, it will not generally do to use too large a capacity, because the voice currents become so much distorted in form as to become indistinct, even though their strength may not be appreciably affected.

29. A non-inductive resistance offers exactly the same opposition to an alternating, or rapidly fluctuating, current as to a direct current. This opposition is equal to its resistance only; that is, the frequency has no influence on the strength of current that a non-inductive resistance will allow to flow through it. The usual manner of representing

inductance, *choke*, *retardation*, or *impedance* coils, as they are variously called, is shown at R or R'', Fig. 9. The addition of an armature, as shown at R', makes a relay or other electromagnetic device out of it. Non-inductive resistances are represented as at r, r'.

The direct current from the battery B will flow through R, r, which are in parallel, then through R', r', R'' back to the battery. The alternating current generated by the alternating-current dynamo D, or any other source of alternating currents, as the secondary winding of an ordinary telephone induction coil, will flow most readily through r–C–b–C'–D. Some may flow through R–R' and also through a–B–R''–r'. But if the frequency of the current and the inductances

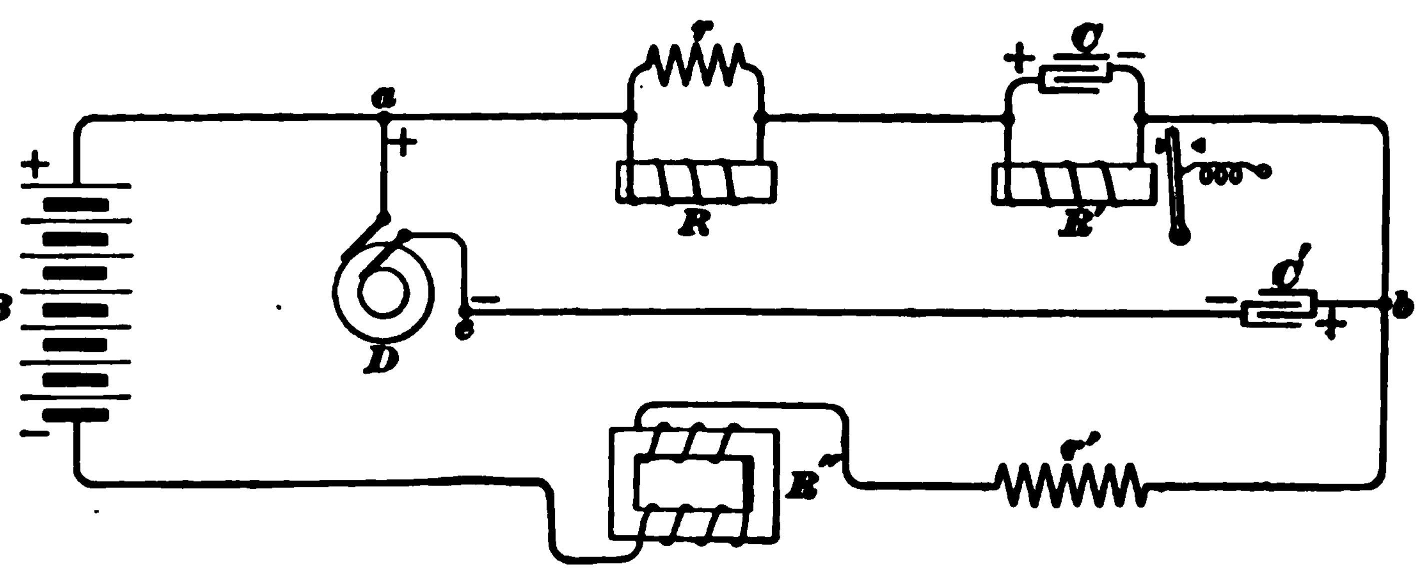


Fig. 9

of R, R', R'' be made sufficiently great, most of the alternating current will flow through r and most of the direct current through R. By making the capacity of C large enough, practically all the alternating current, if not too low in frequency, will pass through it in preference to passing through R', and all the direct current must pass through R'–b–r'–R''–B. By making the inductance of R'' large enough, all the alternating current may be practically excluded from the circuit a–B–R''–r'–b.

When D produces a positive potential at a and a negative potential at e, a positive charge flows to the plates of the condenser C connected toward a and a negative charge to the side of C' connected toward e; that is, a current then flows momentarily from C' through e–D–a–r to C. The positive

charge on one side of C attracts a negative charge to the other side, and the negative charge on one side of C' attracts a positive charge on the other side of C'; hence, a current flows momentarily from C through b to C'. When D reverses the polarity of a and c, the polarity of the charges and the direction of the flow of the currents are also reversed. When only a direct current is flowing, C will merely remain charged to the difference of potential across the coil R'; there will be no flow of charges in and out of it as long as there is no change in the strength of the current flowing in R'.

30. A very rapidly fluctuating, or undulating, direct current may be considered as an alternating current superimposed on a direct current. As a matter of fact, the direction of such a current in a circuit does not change; but the rapid variations in its strength are readily transmitted through a non-inductive resistance or condenser, while only the steady portion of the current can readily pass through an inductive resistance. Hence, a condenser or non-inductive resistance in parallel with an inductive resistance will allow the transmission of a very rapidly fluctuating direct current through the combination, because the fluctuating portion may be considered as being transmitted through the condenser or non-inductive resistance, and the steady portion through the inductive resistance. For such purposes, the non-inductive resistance will usually be relatively high and the inductive resistance relatively low.

ELECTRICAL PROPERTIES OF TELEPHONE LINES

31. Resistance.—The resistance of a telephone circuit has two components: first, the resistance of all apparatus connected in the circuit; and second, the resistance of the line wire itself. The resistance of the line wire may be determined from tables or by direct measurements. A moderate amount of resistance does not in itself seriously interfere with telephone transmission; but resistance in combination with electrostatic capacity may impose a very serious obstacle.

In many of the toll lines, and especially party lines having instruments connected in multiple, the resistance of the line wire often seriously affects the ringing of the call bells at distant stations, thus limiting the number of instruments that can be placed on a line, or rendering exceptionally powerful generators necessary. Of course, this difficulty is met with to the greatest extent where those toll lines are constructed of iron, as an iron wire possesses practically six times as great a resistance as a copper wire of the same size. In this connection, it may be stated that no more than ten 1,000-ohm bells should be connected in parallel across a line circuit, if the resistance of the line wire itself is more than 1,000 ohms.

32. Insulation.—The insulation of a line is the degree to which the line is insulated from the ground or from other conductors. If the resistance measured through the insulating materials from the line wire to the ground or to other conductors is very high, the insulation is said to be good; if very low, it is said to be poor. A properly constructed aerial telephone line should, in dry weather, have an insulating resistance of from 2,500 to 3,000 megohms per mile. This means that the resistance of all the leakage paths from a line wire (not purposely grounded) to other conductors and to the ground measures from 2,500 to 3,000 megohms for 1 mile of wire. In damp weather it may drop to a few hundred thousand ohms per mile. Of course, all leakage on a telephone circuit forms a by-path through which a part of the current flows, thus reducing the amplitude of the wave that reaches the distant end of the line. Leakage in itself does not tend to destroy clearness, but only to reduce the loudness. The advantages to be obtained by very high insulation on long lines are, in a measure, offset by the fact that a certain amount of leakage tends to reduce the condenser action between the two sides of the line by allowing the static charges to leak across and thus prevent, in some measure, the injurious effects of capacity on the form of the waves. This accounts for the fact that certain telephone

lines apparently work better in wet weather than in dry, a fact that is very puzzling to explain until viewed from this standpoint.

An increase in the moisture in a cable increases its electrostatic capacity; hence, a rise in the capacity of a cable conductor is a pretty sure indication that the insulation is deteriorating on account of a defective joint or hole in the lead sheath through which moisture is being absorbed.

33. Inductance.—The inductance of a telephone circuit is almost entirely concentrated in the electromagnets connected in its circuit, and its effects are, therefore, so far as the line wire is concerned, but slight, and may, when a line is properly constructed, be neglected. It has been shown that inductance tends to increase the apparent resistance of a circuit to alternating currents, this increase of apparent resistance being due to the electromotive force of self-induction, which tends to oppose the electromotive force impressed on the line, and, therefore, to cut down the current flowing, in much the same way as an increase in ordinary resistance would do. It has been found, by experiment, that the inductance of complete metallic line circuits of copper makes the impedance but little greater than the resistance. Since inductance tends to neutralize the bad effects of capacity, an increase in the inductance of line circuits is desirable. For this reason, the copper conductors in some recent, short, submarine, telephone cables have had small iron wires twisted spirally around them, so as to increase their distributed inductance. The beneficial effect produced in this manner is only available on heavy conductors with a large cross-section and low resistance. Otherwise, the iron wires increase the diameter and capacity of the cable more than they increase the inductance. On some cables, the use of iron wire around the copper conductor is said to have increased the quality of transmission about 8 per cent. or more.

34. Distributed Capacity.—The great enemy in long-distance telephone transmission is distributed capacity; that

is, the capacity of the line circuit itself. Over 10 years ago, Mr. Heaviside proved, mathematically, that the defects due to distributed capacity could only be remedied by distributed inductance and that the insertion of inductance coils in a line should improve the articulation. But until Prof. M. I. Pupin took hold of this problem, all experimental attempts to profit thereby were failures. To the latter is due the credit of proving, experimentally, that Heaviside's theory was correct, and that by properly designing and locating the inductance coils in a line circuit the distorting effect of distributed capacity can be neutralized by these distributed inductance coils and that more distinct conversation can be held not only over very much greater distances, but also over smaller wires.

Every telephone line may be considered as one plate of a condenser. If the circuit is a grounded one, the single line wire corresponds to one plate of the condenser, the insulation or atmosphere to the dielectric, and the earth, or surrounding conductors, to the other plate. If the circuit is metallic, one of the wires forms one plate of the condenser, the air between the two wires being the dielectric, and the other wire forms the other plate. The capacity of a line is distributed throughout its entire length, and is therefore termed

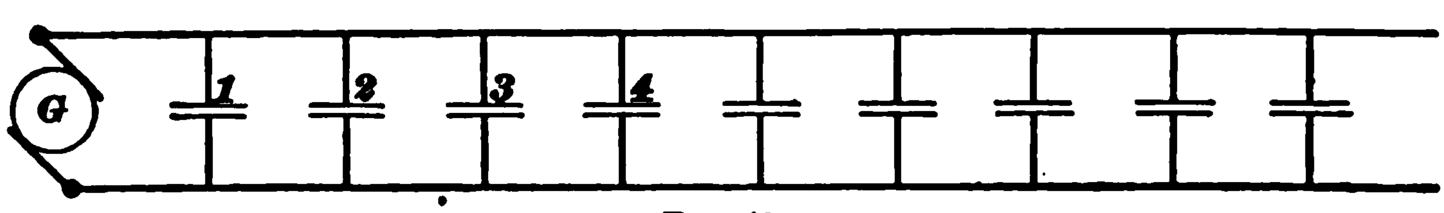


FIG. 10

distributed capacity; each element or short piece of the line wire may be considered as forming one plate of a condenser, the other plate of which is formed by corresponding portions of surrounding conductors. The line circuit may therefore be considered as an infinite number of small condenser plates, each acting on alternating currents flowing over the line, according to the laws already pointed out in the consideration of alternating currents.

35. The action of distributed capacity may be made more clear by considering a number of condensers bridged

across a metallic circuit, as shown in Fig. 10, instead of considering each successive element of the line wire as a portion of a separate condenser. If the electromotive force of the generator *G* placed across the line circuit at one end is suddenly raised, current will be sent over the line, a portion of it flowing into each condenser, the condenser plates keeping at the same potentials as those points of the wire to which they are connected. Condenser *1* will receive the greatest portion of the charge, because it is subjected to the highest difference of potential. Condenser *2*, owing to the resistance of the line wires between *1* and *2*, will be subjected to a slightly smaller difference of potential, and hence will receive a slightly smaller charge, and so on throughout the entire number, the current flowing into each condenser and, of course, detracting from the amount flowing into the more distant portions of the line. If the electromotive force continues long enough in that direction, a sufficient quantity of current will flow through the line to charge all the condenser plates to the full amount; but if the electromotive force continues only long enough to allow sufficient current to flow through the line to charge condenser *1*, the charge in each successive condenser being less and less, the last few condensers will receive practically no charge.

When it is stated that condenser *1* will be charged before condenser *2*, it must not be imagined that this slowness on the part of *2* in taking its charge is due to the speed at which an electric wave may travel along a conductor. This speed may be equal to that of light, 186,000 miles per second, and on the longest line obtainable, the time necessary for an electric impulse to flow through it may be almost too small to measure. It should rather be looked at in the following light: The amount of electricity, in coulombs, that will flow through a conductor depends on the number of amperes flowing and on the length of time the current continues to flow. The charge of a condenser may be measured in coulombs, 1 coulomb being that amount of electricity represented by a flow of 1 ampere for 1 second. Obviously, here is a time element that is not dependent on the actual velocity

of electricity. If 1 ampere flows into a condenser for $\frac{1}{2}$ second, the charge assumed by the condenser during that time will be $\frac{1}{2}$ coulomb, and in $\frac{1}{4}$ second will be $\frac{1}{4}$ coulomb. Similarly, the amount of electrical energy that can flow through a conductor depends on the strength of the current, the voltage, and the time of the flow.

36. If at a given instant an electromotive force in one direction is impressed on such a line as is shown in Fig. 10, there will be a rush of current into the line wire that will tend to charge the condensers; the potential at the terminals of condenser *1* will be greater than that at the terminals of condenser *2*, and similarly, that at *2* will be greater than that at *3*, and so on, this difference of the potential across the various condenser terminals being due to the drop caused by the ohmic resistance of the line wire. Condenser *1* will, therefore, take the greater charge, condenser *2* a somewhat smaller charge, and so on through each successive condenser. If condensers *1*, *2*, *3*, and *4* have the capacity to take a certain amount of charge when subjected to the potentials mentioned, and the electromotive force impressed on the line acts only long enough to allow that amount of current to flow from the source, and then reverse, it is evident that condensers *1*, *2*, *3*, and *4* will each take their respective charges, and the small amount of electricity that flowed from the generator is insufficient to charge the condensers beyond. There will, therefore, be no appreciable flow of current in the line wires beyond condenser *4*, for on the reversal of the electromotive force, the charges of the various condensers will merely flow back to the source. It is not difficult to see, therefore, that a rapidly alternating electromotive force may be impressed on one end of such a line without any of the current impulses ever reaching the other end, the time between the successive impulses being insufficient to allow a sufficient quantity of electricity to flow through the line to charge all the condenser plates. If, now, each small portion of the line wire be considered as a condenser plate, it will be seen that the effect will be practically the same as that illustrated in Fig. 10.

37. The CR Law.—The length of time necessary for an impulse of current to reach the distant end of a line depends not only on the distributed capacity of the line, but on the resistance of the line wire itself. It has been proved by extensive experiments in telegraphy that the length of time required for a current to reach its maximum at the distant end of the line varies directly as the product of the capacity of the line and its resistance. Mr. Preece, chief electrician of the British Post-Office Department, has applied this rule to telephony in the following manner: If the product of the capacity, in microfarads, and the resistance, in ohms, of a copper circuit exceeds 15,000, telephonic transmission over that circuit is impossible. This rule he based on the fact that for the average frequency of telephone transmission, the impulses of current would not have had time to reach the farthest end of the line, and those impulses corresponding to the lower frequencies would be so unduly distorted as to render the results unintelligible. While there seems to be little doubt but that the **CR Law** should be applicable to telephony as well as to telegraphy, there is much doubt as to the correctness of Mr. Preece's constant, 15,000.

In fact, it has been proved in this country, time and again, that good transmission may be had over lines whose CR product greatly exceeds 15,000, causing the CR law, when applied to telephony, to fall into disrepute. The fact remains, however, that the product CR has a direct influence on the difficulty with which speech may be transmitted, and it is therefore well to bear in mind that in the design of telephone circuits this product should be kept as low as possible.

38. The electrostatic capacity of overhead wires, suspended at a height of about 30 feet above the ground, is approximately as shown in Table I.

The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially if any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. It will also vary with

the number of insulators per mile and the moisture on them. When one overhead wire is grounded at one end only (insulated at the other end) the capacity is twice as

TABLE I

Number and Gauge	Diameter Inches	Capacity, in Microfarads per Mile, 30 Feet Above Ground	
		Between One Wire and Ground (Grounded at Both Ends)	Wire to Wire, 12 Inches Apart
1	2	3	4
8 B. & S.	.128	.00958	.00854
9 B. & S.	.114	.00946	.00835
10 B. & S.	.102	.00935	.00818
12 B. & S.	.0808	.00913	.00785
14 B. & S.	.0641	.00892	.00754
16 B. & S.	.0508	.00871	.00726
12 B. W. G.	.109	.00942	.00828
14 B. W. G.	.0830	.00915	.00788

great as when both ends are grounded, that is, twice as great as the capacity given in column 3, Table I. When a high inductance, such as a high resistance (1,200-ohm) bridging

TABLE II

Height of Wire Above Ground Feet	Capacity Microfarads per Mile	Inductance Henrys per Mile
10	.01060	.002796
20	.009796	.003019
30	.009379	.003149
40	.009105	.003242

bell, is connected between the end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is insulated.

The capacity and inductance of one copper wire, .104 inch in diameter, weighing 173 pounds per mile, with both ends grounded is given in Table II.

TABLE III

Height Above Ground Feet	Capacity Between Wire Grounded at Both Ends and the Ground Microfarads per Mile	Capacity Between Two Wires (Distant Ends Open) Microfarads per Mile	Inductance of One Wire Grounded at Both Ends Henrys per Mile	Mutual Inductance of Two Wires Connected Together at Distant End Henrys per Mile
20	.01171	.004732	.003019	.001187
30	.01150	.004936	.003149	.001318

The capacity and inductance, when two grounded circuits of copper wire, .104 inch in diameter, are suspended at the same height and 1 foot apart, are given in Table III.

The increase of capacity between one wire and ground, due to the adjacent grounded circuit, is .01171 − .009796 (see Table II) = .001914, or 19.6 per cent. at a height of 20 feet, and .0115 − .009379 = .002121, or 22.6 per cent. at a height of 30 feet.

TABLE IV

Separation Inches	Capacity Microfarads per Mile	Inductance Henrys per Mile
10	.008503	.003546
12	.008218	.003663
14	.007992	.003762
16	.007806	.003848
18	.007649	.003924

The capacity and inductance of metallic circuits of copper wire, .104 inch in diameter, for various separations are given in Table IV.

NOTE.—As the electrostatic capacity of bare overhead and cable conductors can be computed only by formulas involving logarithms, a knowledge of which has not been considered necessary in order to pursue this subject, the rest of this Section may be omitted. However, for the benefit of those who may understand that subject, the two formulas that were used to calculate Table I are given.

39. The electrostatic capacity of a single wire of length l and diameter d at a height h in the air above the ground, when grounded at both ends, may be theoretically calculated by the formula:

$$C = \frac{.0388 \times l}{\log_{10}\left(\frac{4h}{d}\right)} \text{ microfarads} \qquad (1)$$

The electrostatic capacity of two parallel wires, each of length l and diameter d at a distance h from each other, may be theoretically calculated by the formula:

$$C = \frac{.0194 \times l \times K}{\log_{10}\left(\frac{2h}{d}\right)} \text{ microfarads} \qquad (2)$$

In these two formulas, l must be expressed in miles, because the constant is based on that unit; but h and d may be expressed in any units of length, provided that both are expressed in the same units, because $\frac{h}{d}$ is merely a ratio. For instance, the value of the ratio is the same whether h and d are both expressed in feet or both in inches. K is the inductivity of the dielectric filling the space between the two wires; and for a bare overhead line $K = 1$. Values calculated by these formulas agree closely enough with results obtained for bare overhead wires by actual measurement. The effect of adjacent circuits is to increase the effective capacity of a line as determined by the above formulas.

40. If the two parallel wires of a metallic circuit have an insulating covering, in addition to being suspended a distance apart in air, the capacity is slightly increased by the greater inductivity of the insulating covering. If the wires are of diameter d, the insulating covering of diameter d_1,

at a distance h from each other, and the inductivity of the insulating covering is K, the length in miles l, the capacity, in microfarads, is given by the formula:

$$C = \frac{.0194 \times l}{\log_{10} \frac{2h}{d_1} + \frac{1}{K} \log \frac{d_1}{d}} \qquad (1)$$

The mutual capacity C, in microfarads, between two two-wire metallic aerial circuits, of length l in miles, one circuit consisting of wire of diameter d_a and the other of wire of diameter d_b, is given by the formula:

$$C = \frac{.15536 \log_{10} \frac{r_1 \times r_2}{r_3 \times r_4} \times l}{16 \log_{10} \frac{2r_5}{d_a} \times \log_{10} \frac{2r_6}{d_b} - \left(2 \log_{10} \frac{r_1 \times r_2}{r_3 \times r_4}\right)^2} \qquad (2)$$

The distances r_1, r_2, r_3, r_4, r_5, r_6 are shown in Fig. 11.

These formulas are correct for wires of magnetic or non-magnetic material. The presence of the earth beneath an aerial metallic circuit increases the capacity very slightly, less than a fraction of 1 per cent., if the wires are above the earth a distance at least several times the distance between them. The assumption made in the deduction of the formulas for electrostatic capacity is that there are no other wires in the immediate vicinity of those being considered. The effect of adjacent circuits is to increase the effective capacity of a line. For a pair of conductors in a telephone cable, the formula would be too complicated to be of any practical value (even if one could be derived), on account of the influence of neighboring conductors and the grounded lead sheath.

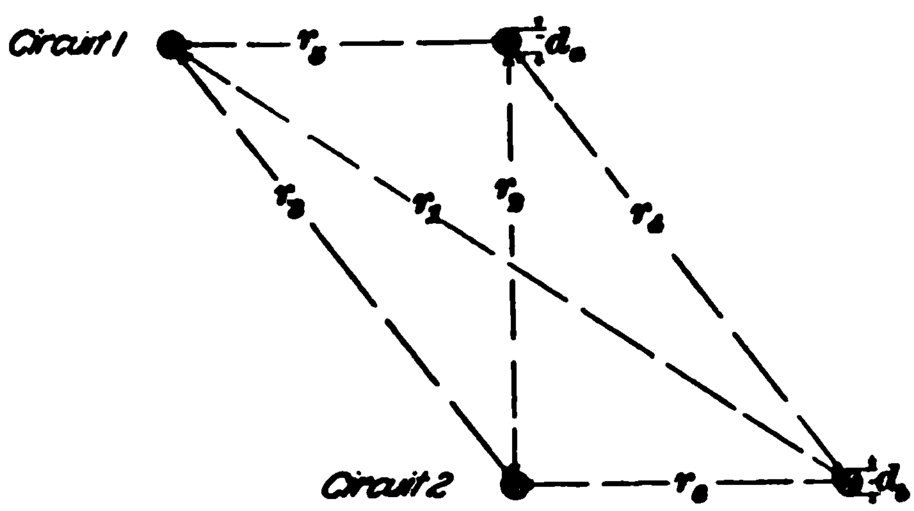


Fig. 11

The formula for the inductance of a single aerial wire, composing a grounded circuit, is:

$$L = \left(\frac{.08047 + .7411 \log_{10} \frac{2h}{r}}{10^3}\right) \qquad (3)$$

where L = inductance per mile, in henrys;
h = height of wire above earth;
r = radius of wire.

h and r should be expressed in the same units. The inductance of a two-wire aerial metallic line may be expressed by the formula:

$$L = \left(\frac{.1609 + 1.482 \log_{10} \frac{d}{r}}{10^3}\right) \qquad (4)$$

where L = inductance per mile of the line circuit, in henrys;
d = distance between centers of two wires;
r = radius of either wire.

d and r should be expressed in the same units. Both of the above formulas are for wires made of non-magnetic material. The inductance of iron or steel wire is greater than that of copper wire of the same size. The effect of the earth on the inductance of a metallic circuit is less than a fraction of 1 per cent. if the wires are above the earth a distance greater than two or three times the distance between them. The inductance is decreased by the presence of the earth. These formulas assume that there are no magnetizable substances within a distance of the circuits less than several times the distance between the wires of a pair, or the height of a wire above the earth.

The mutual inductance M between two two-wire metallic aerial circuits is given, in henrys per mile, by the formula:

$$M = \frac{.7411 \log_{10} \frac{r_1 \times r_2}{r_3 \times r_4}}{10^3} \qquad (5)$$

in which the distances r_1, r_2, r_3, and r_4 are the same as in Fig. 11.

If, in formulas 2 and 5, the distances are such that $r_1 \times r_3 = r_2 \times r_4$, C and M become equal to zero; therefore, it is possible to arrange two two-wire metallic circuits so that there shall be no electrostatic or electromagnetic interference between the two circuits; in other words, there would be no cross-talk, which will be explained later, between two circuits so arranged.

TELEPHONE RECEIVERS

COMMERCIAL TYPES OF TELEPHONE RECEIVERS

MAGNETO-TELEPHONES

1. By a **magneto-telephone** is meant that class of instrument originated by Bell, the essential parts of which are a permanent magnet carrying one or more coils at its extremity or extremities, a diaphragm of magnetic material mounted in proximity to the poles of the magnet, and a suitable casing and framework binding the whole structure rigidly together. Such instruments are now used almost entirely as receivers, although they may also be used as transmitters.

2. Importance of Mechanical Details.—A **receiver** may be formed from almost any permanent magnet having a coil of insulated wire about it and associated with a light soft-iron armature; in fact, apparatus designed for entirely different purposes have often been found to work as receivers. But for commercial service, a receiver should be made with fully as much reference to perfection in mechanical construction as to electrical efficiency.

3. Classification.—Commercial telephone receivers may be divided into two general classes; namely, *single-pole* and *double-pole*, or *bipolar*. In the former, a permanent magnet is so arranged as to present one pole only to the vibrating diaphragm; while in the latter class, the permanent magnet is of substantially a horseshoe form, thus presenting

both poles to the diaphragm. A third class might be added embracing *multipolar receivers*, which would include all those having permanent magnets presenting more than two poles to the diaphragm. Many attempts have been made to improve the efficiency of the receiver by thus multiplying the number of poles, but these have not proved very successful, and have not been extensively used.

SINGLE-POLE RECEIVERS

4. Bell Single-Pole Receiver.—The single-pole receiver extensively used for years by the American Bell Telephone Company in the United States, is shown in Fig. 1. *M* is a compound magnet composed of two pairs of perma-

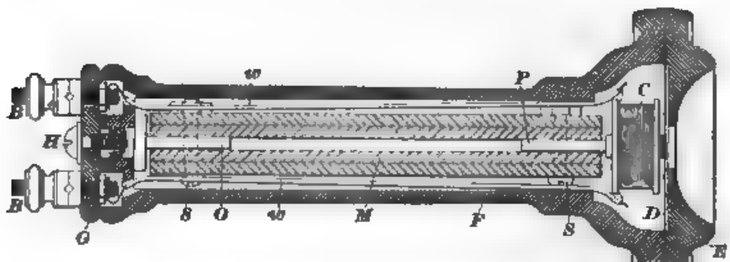


FIG. 1

nently magnetized steel bars with like poles together. These pairs of bars have clamped between them at one end a soft-iron pole piece *P*, and at the other end a block *O*, also of iron. The parts of the pole piece *P* and of the block *O* that lie between the pairs of magnets are flattened in such manner as to present a large contact surface to the magnets that rest against them. The projecting end of the pole piece *P* is cylindrical and has wound on it a coil *C* of fine, insulated, copper wire, usually No. 38 B. & S. gauge. The magnet and its coil are incased in a shell of hard rubber composed of three parts, *E*, *F*, and *G*. Between *E* and *F*, which screw together in the manner shown, is clamped a soft-iron diaphragm *D*, the space between the diaphragm and the pole piece being about $\frac{1}{64}$ inch. This diaphragm is stamped

from ferrotype metal, such as is used by photographers in making tintypes. This metal is rolled from a very fine quality of iron, the thickness being from .009 to .011 inch. Two binding posts *B*, *B* are secured to the tail-piece *G* of the shell, and these are connected by heavy wires *w*, *w* to the terminals of the coil *C*. The screw *H* passing through the tail-piece engages a tapped hole in a cylindrical extension of the block *O*, thus holding the tail-piece *G* in position against the shell *F*, and also firmly securing the magnets *M* to the rear end of the shell. Before putting the tail-piece in position, the binding posts *B*, *B* are secured in place on it by the small nuts, as shown, after which the leading-in wires *w*, *w* are firmly soldered to the inside ends of these posts. These wires are then cut to the proper length and pushed through the tube of the shell as the tail-piece is placed in position. The fine-wire terminals of the coil *C* are then wrapped around the ends of the leading-in wires and soldered. The resistance of the coil of this receiver is 75 ohms.

5. Mechanical Defects.—The fact that this receiver was almost universally used by the American Bell Telephone Company for many years has proved that it is capable of giving good and long-continued service; it is, however, subject to several inherent faults, of a mechanical nature, that greatly impair its efficiency at times and cause much trouble. The principal one is due to the fact that genuine or imitation hard rubber and steel expand and contract under the influence of heat or cold at very different rates. This causes the distance between the pole piece and the diaphragm to vary with changes in temperature, sometimes to such an extent as to noticeably affect the talking qualities in the instrument. In cold weather, it not infrequently happens that the diaphragm will be drawn up against the pole piece, thus rendering the receiver totally inoperative. This is technically known as *freezing*. The various methods that have been used to eliminate the trouble due to unequal expansion of the shell and magnet will be apparent from the following illustrations and descriptions of receivers.

Bipolar receivers are very extensively used in all parts of the world, and in the United States have almost entirely replaced the single-pole instrument.

BIPOLAR RECEIVERS

6. Bell Pony Receiver.—The bipolar receiver, extensively used by the Bell Company, is shown in Fig. 2. The magnet *M* is composed of two bars of magnet steel, approximately 4 inches in length, secured to a small cylindrical iron block at their rear ends by a bolt, as shown. Opposite poles of the magnet are placed together, thus making the two bars form a complete horseshoe magnet, the poles being at

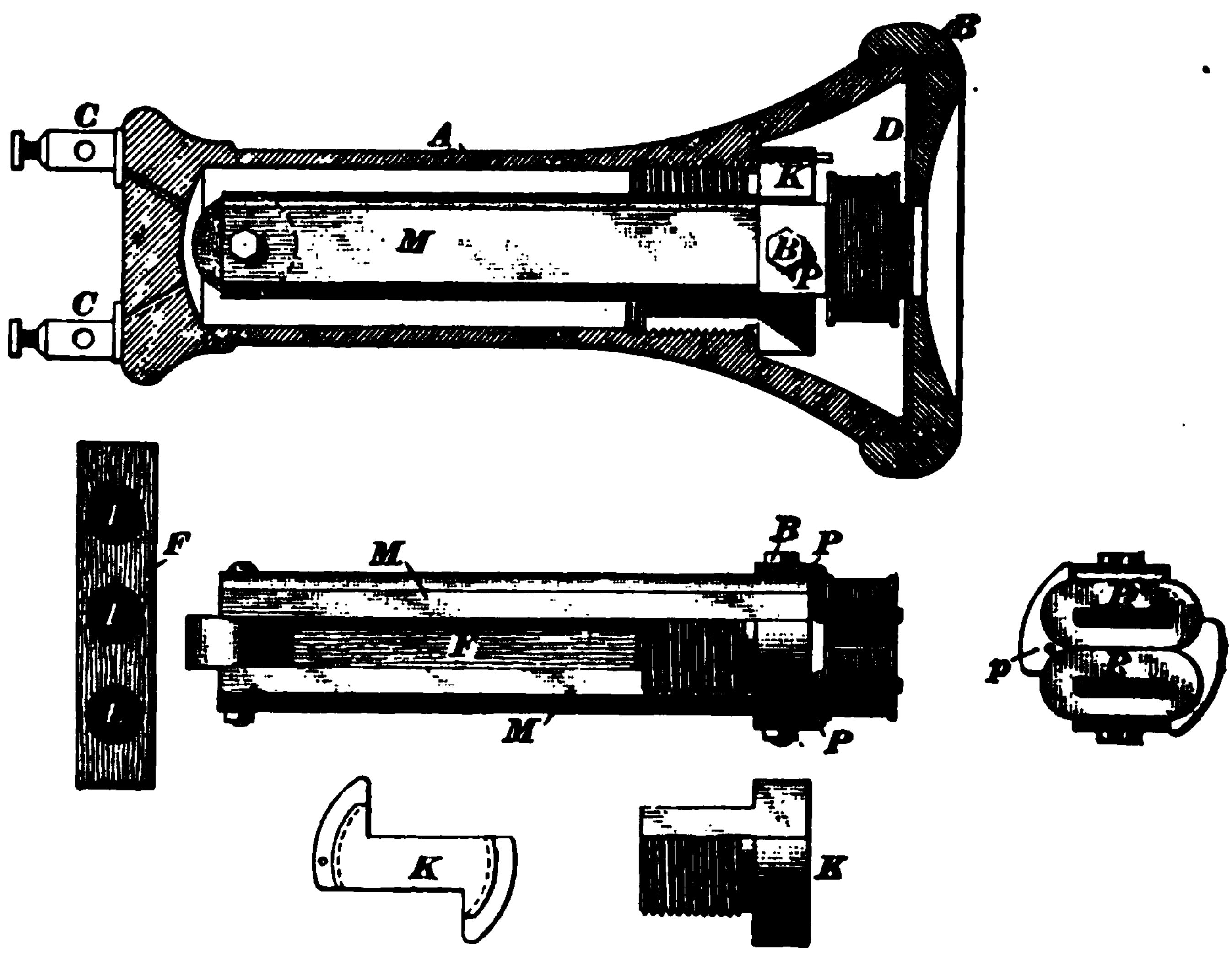


FIG. 2

the two free ends. Between the polar ends of this horseshoe magnet is clamped a brass adjustment block *K* of the form shown in the lower part of Fig. 2. On the outside of the polar extremities of the magnet are clamped two soft-iron pole pieces *P*, *P*, which are secured to the magnet by the same bolt *B* that clamps the magnets to the block *K*. On the flat pole pieces are forced brass or German-silver washers

adapted to fit tightly in place, and thus retain their position. In this manner, the spools are formed on which the wire of the coils is wrapped. Before wrapping on the wire, however, the spool is thoroughly insulated with paper, which is fastened around the core and to the inside of metal heads with shellac.

The shell is of two pieces *A* and *B*, which clamp the diaphragm *D* between them in the usual manner. In the piece *A* of the shell is cut an internal screw thread into which the screw thread on the brass block *K* fits. The block is turned within the shell *A* until the proper adjustment between the diaphragm and the pole pieces is obtained, and is secured in that position by a pin *p* that passes through the shoulder on the block and into the hard rubber, as shown. This maintains the adjustment permanent and prevents meddlesome persons from unscrewing the magnets. The rear end of the magnet is not supported in the shell, and inasmuch as the only support of the magnet in the shell is at a point comparatively close to the diaphragm, no trouble has been experienced due to the unequal expansion or contraction, as in the cases where the magnet was supported in the shell at the end farthest from the diaphragm. The leading-in wires are soldered to the binding posts *C*, *C*, which are then secured in position on the shell by means of screws passing through flanges on the binding posts and into the hard rubber of the shell. The wires are led through recesses between the block *K* and the shell to the coil chamber, and the fine-wire terminals of the coils are soldered to them in the ordinary manner. This receiver is exceedingly neat in appearance, efficient in operation, and convenient to handle; it is considerably smaller than the single-pole receiver of the Bell Company, and has proved superior to it in every way.

In order to give this receiver sufficient weight to operate the switching devices usually provided with complete telephones, it was found necessary to place between the limbs of the magnet a block of wood *F* containing several small lead cylinders *l*, previously molded into the wood. Receivers of this type present both a north and a south pole to the

diaphragm at a point very near its center. Hence the magnetic circuit of the permanent magnet is made practically complete by the diaphragm, the only air gap being that between the diaphragm and the pole pieces. In this way, the field in which the diaphragm operates is greatly strengthened and a slight movement of the diaphragm toward the pole pieces produces a shorter air gap and therefore a better path for the magnetic lines from one pole piece to the other, and consequently a stronger pull than would be the case with the same current in a single-pole receiver. For common-battery systems, the two coils of this receiver are wound with No. 36 B. & S., and connected in series, giving a resistance of about 60 ohms, although they have been wound to as low as 20 ohms. For local-battery systems, 100 ohms is the usual resistance.

7. Western Telephone Construction Company's Receiver.—Fig. 3 shows a receiver of the Western Telephone

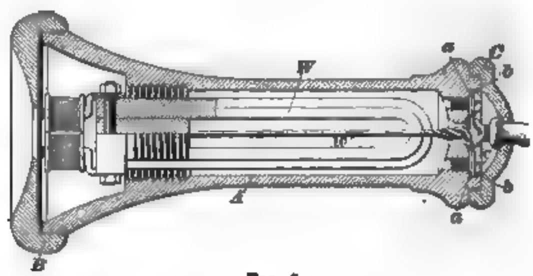


FIG. 3

phone Construction Company, which is almost identical with that of the Bell Company, with the exception of the method of attaching the receiver cord and the establishing of the connections between its conductors and the wires leading from the coils. The shell is composed of three parts *A*, *B*, and *C*, all of hard rubber, as shown. The leading-in wires *w* terminate in two small washers *a*, *a* secured directly to the piece *A* of the shell. The receiver cord is provided with similar washers *b*, *b*, adapted to be held in contact with the washers *a*, *a*, by means of the screws *c*, *c* passing into the hard rubber. The

receiver cord is also provided with a shoulder or enlargement at a point near the terminals, this being of such a size that it will not pass through the opening in the tail-cap *C*. This cap is slid on to the cord from its free end, and, after the cord has been connected to the receiver terminals, is secured to the part *A* of the shell by means of a screw thread. This arrangement effectually prevents any strain coming on the cord terminals or the connectors when the receiver is dropped or hung by the cord. Such strains as these often cause breakage at the terminals of the cord, thus rendering the receiver inoperative.

8. The Ericsson Receiver.—An excellent bipolar receiver, manufactured in Sweden by the L. M. Ericsson Company, of Stockholm, but imported into the United States

FIG. 4

to a considerable extent, is shown in Fig. 4. The magnets, which are very strong, are formed of a single bar of steel *M* (.62 inch wide and .2 inch thick) bent into a horseshoe form, 4 inches long. These carry pole pieces of soft iron secured directly to the magnet ends by means of small machine screws. The cup containing the coils is of brass, and is secured to a thin brass tube *T* incasing the magnets. Over this tube is tightly fitted a thin hard-rubber tube serving as a handle. The magnets are secured within the shell by means of two fillister-head machine screws projecting through slotted holes on the opposite sides of the tubular portion of the shell and engaging tapped holes in the magnet itself. The binding posts are mounted on a hard-rubber block *V*, which is screw-threaded into the end of the brass

tube *T*. Heavy leading-in wires are soldered to these binding posts on the inside of the block *V*, and are secured to the terminals of the coils in a manner already described. The diaphragm, which is $2\frac{1}{4}$ inches in diameter and .01 inch thick, is of tinned sheet iron, and is secured in place by means of the hard-rubber cap or ear piece *C*. Each soft-iron pole piece is $\frac{7}{64}$ inch thick and $\frac{9}{16}$ inch wide and the distance between their centers is $\frac{13}{32}$ inch. When both spools are wound with about 2,000 turns of No. 36 wire, their resistance is 120 to 125 ohms.

This receiver is durable and efficient. The fact that the shell is almost entirely of metal assures a permanent adjustment of the parts when once properly secured. The receiver shown in this figure has exposed binding posts, but a later form has all connections and metal parts concealed within the shelf.

9. **Modern Receivers.**—It is now considered advisable to have no binding posts or other metal exposed on the outside of a receiver where it can come in contact with the hand in the ordinary use of the receiver. This is to avoid all possibility of the user receiving disagreeable or dangerous electric shocks due to lightning or to crosses between the telephone line wires and lighting or power circuits. The absence of exposed binding posts also reduces meddling with the receiver and the working loose of such connections. The terminals of the receiver coil are connected inside the receiver shell to flexible receiver cords, which are long enough to connect to binding posts on the telephone box or case. A strong cord is bound in with the flexible connecting wires and fastened to the receiver magnets and the telephone box so that it receives all the strain should the receiver be dropped or left hanging by the cord.

The receiver should be made strong enough to withstand the rough usage of careless people, and at the same time maintain a permanent adjustment. Many now claim that subsequent adjustment of a receiver is a detriment rather than an advantage, and hence most receivers are now

constructed so that the original adjustment will remain permanent throughout the life of the receiver. This has the advantage that it prevents meddlesome or ignorant persons trying to improve the operation of a receiver by altering its adjustment.

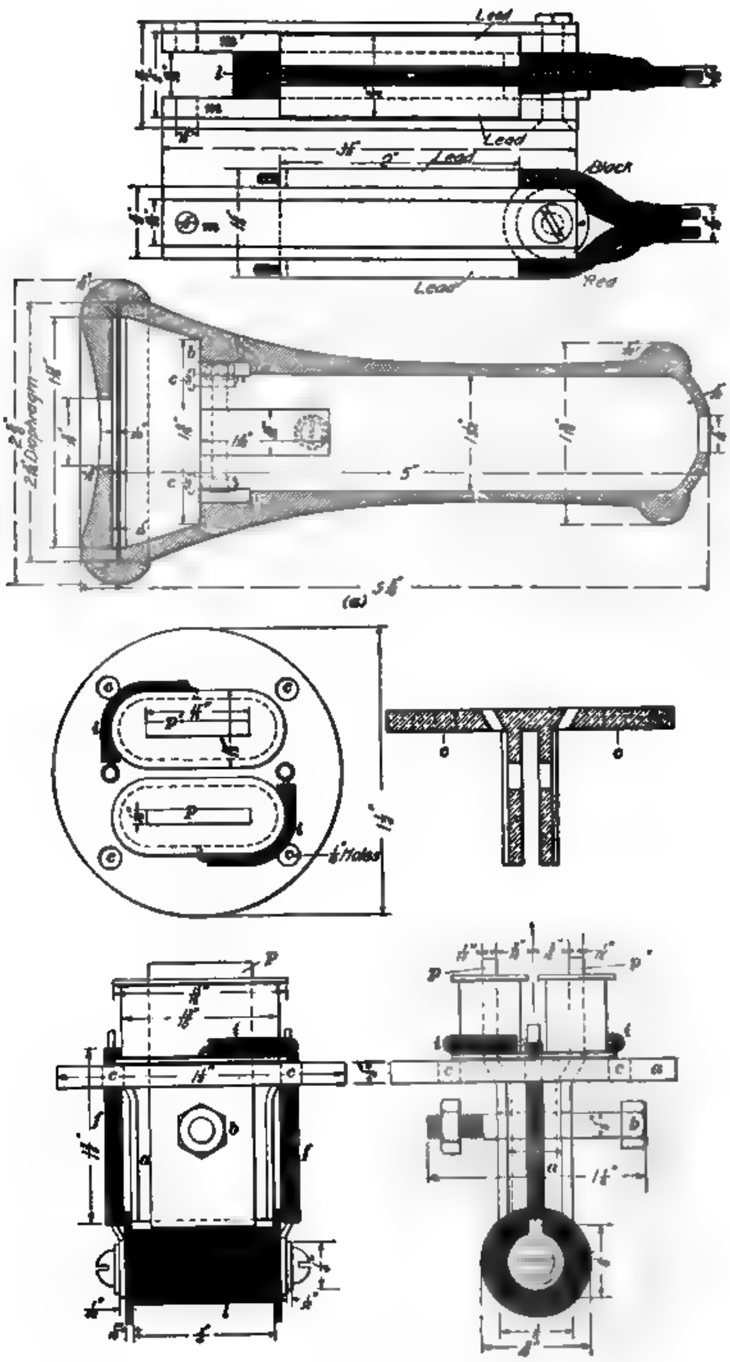
The chamber containing the diaphragm should be of such shape as not to muffle the sound.

Several plans have been devised for remedying the defect due to unequal contraction and expansion of the shell and magnet, one of which is to make a cup that supports the diaphragm of brass, and to firmly secure the magnet, pole piece, and coil to this cup in such manner that the entire working parts of the receiver are firmly bound together by a metal whose coefficient of contraction and expansion is about the same as that of steel. Typical of this class, which are termed **metal-head receivers,** are those manufactured by the American Electric Telephone Company and the Century Telephone Construction Company.

Another method successfully used is to fasten the magnets, pole pieces, and coils permanently to a non-magnetic metal casting that is held usually by four or more screws on a seat forming part of the shell and usually at the base of the coils. Typical of this class are the Holtzer-Cabot and Kellogg receivers.

These two types of receivers, as well as some others, effectually remedy the difficulties spoken of, and when once properly adjusted at the factory, need no further adjustment, and therefore no means of adjustment are provided.

10. The **Kellogg double-pole receiver** is shown in Fig. 5. The two straight-bar permanent magnets *m*, *m'* have a cylindrical piece of iron *o* held tightly between them at one end by a bolt and nut. The pole pieces *p p'*, said to be made of soft Norway iron, fit into a slight recess on each side of a casting *a* of non-magnetic metal, which fills the space between the pole pieces so that the latter bear tightly against the permanent magnets when the nut is tightly screwed up on the bolt *b* that passes through the two pole



(a)

(b)

FIG. 5

pieces, permanent magnets, and the casting *a*. The casting is securely fastened by four brass screws at *c* to the hard-rubber shell at a point near the diaphragm, so that there is little chance for any change in adjustment due to rough handling of the receiver or to the unequal contraction and expansion of hard rubber and metal when the temperature changes. No provision is made for adjusting the distance between the pole pieces and diaphragm after leaving the factory. The metal ends of the spools are fastened by a bit of solder to the pole pieces. There are no binding posts on the outside of the shell; instead, the receiver cord passes through a hole in the shell, and a cord bound in with the conductors is tied around the iron cylinder *o* so as to relieve the conductors and shell of all strain. Between the two permanent magnets is a piece of hard fiber *l*, on each side of which the receiver conductors are electrically connected by brass screws and washers to short pieces of stout wire *f*, *f* that are soldered at their upper ends to the terminal wires *i*, *i* of the coils. Any standard receiver cord may be used with this receiver. All connections are enclosed within the shell so that no metal whatever is exposed on the outside. To get at the connections, it is necessary to remove the cap at the diaphragm end, and the four screws *c* that hold the casting, magnets, pole pieces, and coils to the rubber shell. To make the receiver heavier, the space between the bar magnets is about filled with lead, as indicated in Fig. 5 (*a*), thus insuring good wiping contacts in the hook switch because the additional weight allows the use of a stronger spring to raise the hook. The receiver coils, when wound with No. 30 B. & S. wire and connected in series, have a resistance of 65 to 70 ohms.

11. Holtzer-Cabot Electric Company's double-pole receiver is shown in Fig. 6. The terminals are entirely enclosed within the shell and the cord is given a substantial hitch about the end of the one-piece permanent magnet in such a way that no strain can come on the connections. The permanent magnet is about as strong as that in any

receiver made for general use. The internal arrangement of the parts is shown in the figure. The distinguishing feature of this receiver is the shape of the soft-iron pole pieces. They are nearly semicircular in shape, which seems to give a more uniform distribution of the lines of force through the diaphragm than the ordinary rectangular-shaped pole pieces. The pole pieces are about $1\frac{1}{4}$ inches long, $\frac{15}{32}$ inch wide, and $\frac{5}{32}$ inch thick at the middle. The receivers are permanently adjusted before leaving the factory and the magnetic system is fastened in the shell in very much the same manner as the Kellogg receiver. The coils are wound

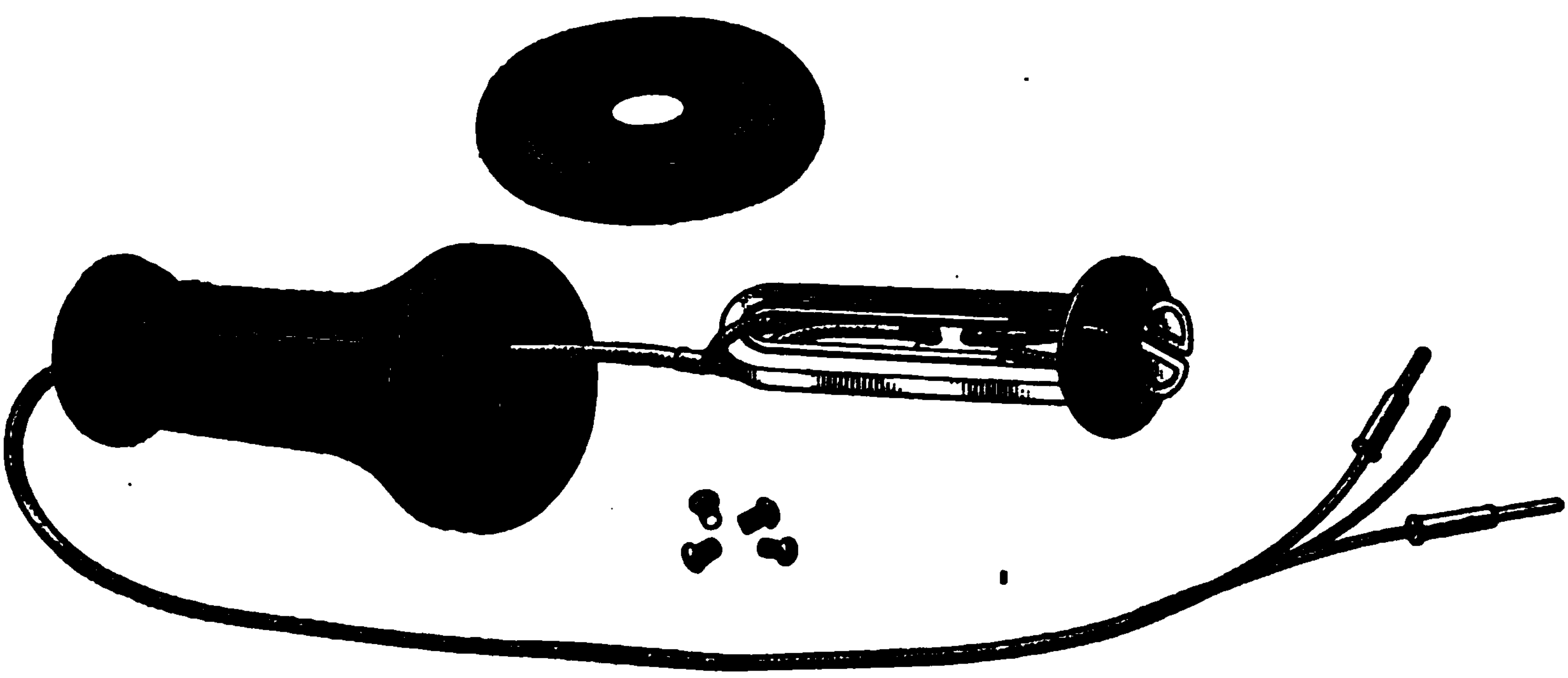


FIG. 6

with No. 36 B. & S. silk-covered wire, and have a resistance of about 75 ohms when connected in series. All exposed parts of the spool and cores are nickel-plated to prevent corrosion. The permanent magnet is about $\frac{5}{8}$ inch wide, $\frac{1}{4}$ inch thick, and $3\frac{1}{2}$ inches long. The diaphragm, which is made of tinned sheet iron, is about 2 inches in diameter and so thick ($\frac{1}{80}$ inch) that it is not magnetically saturated even by the relatively strong permanent magnets used. All parts are made so as to be interchangeable, and the purchaser may obtain either a pure hard-rubber or composition shell and either a silk- or worsted-covered cord.

12. American Electric Telephone Company's Receiver.—The separate parts of the double-pole receiver made by the American Electric Telephone Company are

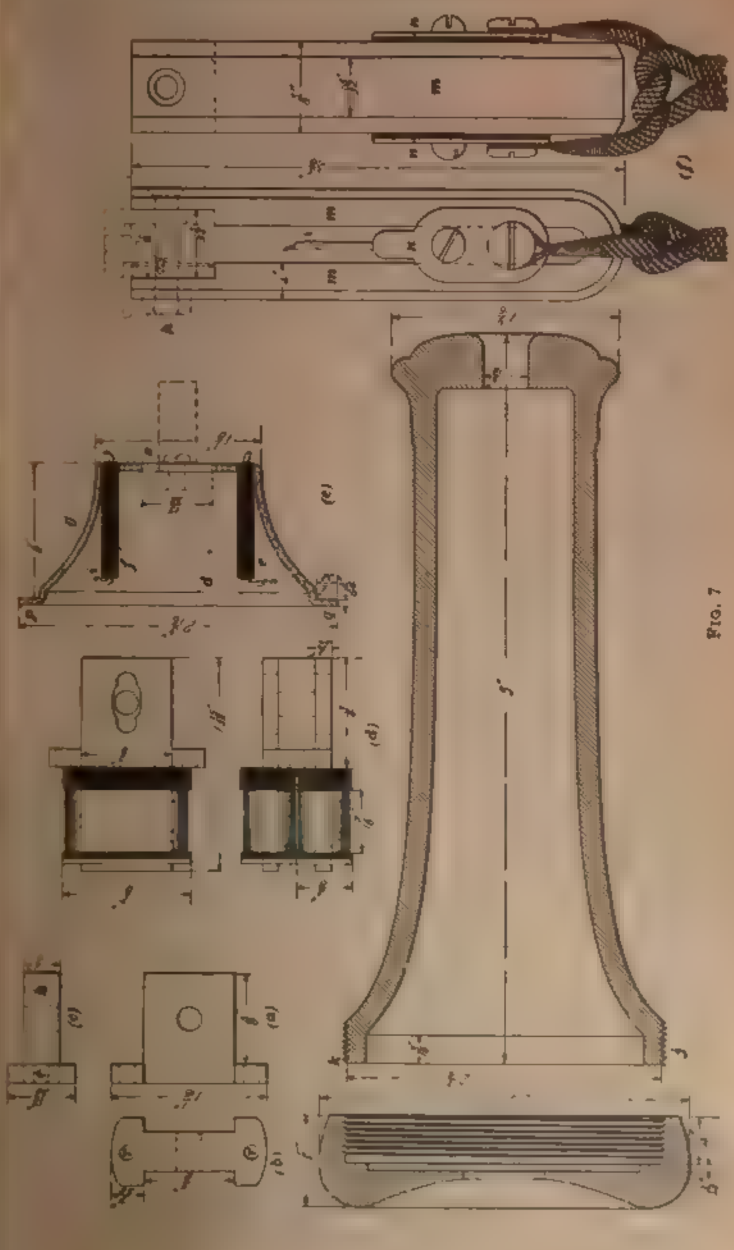


Fig. 7

shown in Fig. 7. The permanent magnet *m* is made of a single piece of steel. Between the two limbs is placed a piece of hard fiber to which the terminal pieces *n*, *n* are fastened with screws. A brass piece, three views of which are shown at (*a*), (*b*), and (*c*), is used to hold the two soft-iron pole pieces and coils (*d*) and the brass cup (*e*) in position on the ends of the permanent magnet, a bolt *h* binding them all together. The cup is fastened to the brass piece by two screws *s* that pass into the holes *r*. The conductors *i* pass through fiber tubes *e*, *f* that are fastened to the brass cup. The lower ends of each of the conductors *i*, *i* are soldered to the pieces *n*, *n* and the upper ends are soldered to two ends of the two coils. The receiver cord is passed through the hole in the rear end of the receiver shell, knotted so that the weight of the receiver will be borne by the knot resting against the shell, and the conductors fastened by screws to the brass pieces *n*, *n*. The diaphragm, which is a flat piece of tinned sheet iron, rests on the rim *pq* of the brass cup. When the magnetic system is placed in the shell, the rim *pq* rests against the shell at *jk* and is held there when the receiver cap is screwed into place.

The strain due to the entire weight of the receiver may be traced from the junction between the brass cup and shell, through the shell, and knot in the receiver cord to the cord. No matter how badly the receiver shell may be broken anywhere back of the screw thread *jk*, the receiver remains in proper adjustment and can be used until the cord conductors wear off where they are fastened to the pieces *n*, *n*. After the receiver is assembled and adjusted by the manufacturer, the adjustment is not supposed to be altered. When the two spools, which are made of brass lined with insulating material, are wound with No. 36 B. & S. silk-covered copper wire, and connected in series, they have a resistance of about 125 ohms. No metal is exposed on the outside of the receiver shell. In some earlier receivers of this make, the pole pieces were ground off to coincide with the surface *pq* and the diaphragm was dished just enough to hold the center portion the correct distance from the pole pieces.

13. Century Telephone Construction Company's receiver is shown in Fig. 8. The distinguishing feature of the receiver is the method of attaching the diaphragm cup to the magnets, which reduces to a minimum the difficulty due to the unequal expansion of different parts of the receiver. Only the ends of the pole pieces project through a metal cup, which can therefore be made very shallow, thereby eliminating what is claimed to be undesirable resonance effects. The cup and pole pieces are ground to give a proper and permanent adjustment. Furthermore, the spools and all connections are protected when the receiver is assembled, and the magnetic system as a whole slips out of the shell when the diaphragm cap is removed. A cord bound in with the receiver conductors is fastened to the permanent magnets, thus relieving the shell and conductors of all strain. The design of this receiver seems to be excellent.

FIG. 8

14. Stromberg-Carlson Telephone Manufacturing Company's Receiver.—This Company has always maintained that a receiver should be capable of adjustment. To conform to the recent demand for a receiver with no metal parts exposed, they now make a so-called all-rubber-shell receiver, as shown in Fig 9, which is about the only modern receiver that may be readily readjusted after leaving the factory. The one-piece permanent magnet is about as strong as any used for this purpose in the United States. The hard-rubber shell is made in two pieces only. The coils and pole pieces *b*, *c* pass through a metal plate *d* and are supported, when in place, by a cast bridge piece *i*, which is milled so as

to receive them and also to fit in between the ends of the permanent magnet *a*, where the three pieces are tightly held by a screw. The magnetic system, when thus assembled, is enclosed by a metal case *h* that is threaded on the inside to fit the thread on the outside of the metal bridge *i* and on the outside to receive the ear cap and shell. The plate *d* rests on a seat in the metal case *h*. This construction renders the diaphragm chamber very nearly air-tight, which it is claimed prevents the surging of the air in the shell of the receiver, which gives rise to undesirable resonant sounds.

FIG. 9

After placing the diaphragm on the metal case, the ear cap is screwed on permanently and then the instrument may be readjusted to any degree of sensitiveness by holding the receiver to the ear with one hand and turning the magnet with the other, at the same time talking into a transmitter connected with the receiver. When the proper adjustment has been obtained, screws that pass through the locking plate *e* are screwed up tight, which results in a tension between the bridge *i* and the metal case *h* and prevents any turning or change in the adjustment. The shell is then screwed on

the metal case h, leaving no metal exposed. The coil and cord terminals are fastened to a hard-rubber block placed between the limbs of the permanent magnet. The weight of the receiver is supported by the knot in the receiver cord. The diaphragm, which is made of tinned sheet iron, is about .01 inch thick and about $2\frac{3}{16}$ inches in diameter. The magnet is about $4\frac{1}{2}$ inches long, $\frac{5}{8}$ inch wide, and $\frac{1}{4}$ inch thick. The soft-iron pole pieces are about $\frac{3}{8} \times \frac{1}{16} \times 1\frac{3}{16}$ inches. The fiber spools are about $\frac{7}{16}$ inch wide, $\frac{7}{8}$ inch long, and $\frac{1}{2}$ inch deep. When wound with about 1,180 turns of No. 38 wire, the two coils connected in series have a resistance of from 90 to 100 ohms.

15. Columbia Telephone Manufacturing Company's receiver is shown in Fig. 10. Its construction will

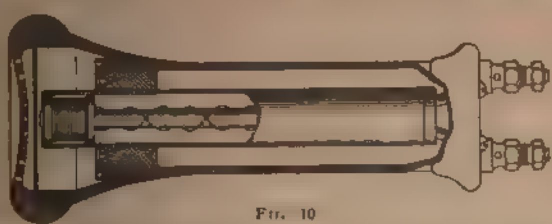


FIG. 10

be readily understood from the figure. The magnetic system consists of a central steel bar, over one end of which is placed the coil, and an iron tube forming the return path for the lines of force; hence, it is practically a double-pole receiver. The rubber ear piece, instead of having one central opening, has a number of small holes. It is claimed that this prevents meddlesome persons from poking the diaphragm with pencils or other objects, but it is doubtful if this construction does not interfere with the progress of the sound through it. This receiver is also made with concealed terminals instead of the outside binding posts shown in this figure.

The **solid receiver** made by Wm. J. Murdock & Company has all parts, except the coils and diaphragm, solidly incased by composition. With such construction, it should be practically impossible for any part to come loose or get

out of adjustment. The first receivers of this construction had external binding posts, but they are now made with the terminals concealed within a tail-piece, which may be removed.

WATCH-CASE RECEIVERS

16. Since **watch-case receivers** are used mostly as operators' head-receivers, they must be as light as is consistent with good construction, and as small and compact as possible; therefore, they are more difficult to make. Furthermore, the short magnets used in them are more easily demagnetized, so that more care is necessary in their construction. The magnets are generally compound, have two poles, and weigh less than 5 ounces. They usually consist of two, three, or four thin magnets laid one on the other with like poles in contact with each other. The pole pieces are generally clamped between them.

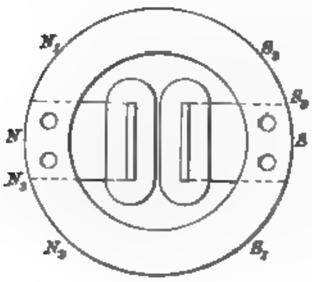


FIG. 11

The magnets of watch-case receivers are punched from sheet metal and are of two kinds, the circular, as indicated in Fig. 11, and the horseshoe, as shown in Fig. 12. Of the two types, the one shown in Fig. 12 is the better, because it retains the magnetism better. The poles of all the magnets may easily be made to come at the ends of the magnets, and all like poles to coincide. The magnetic circuit is much longer, as it includes an arc of nearly 300°. It is also much easier to arrange the binding post, there being sufficient room between the poles. It is a difficult matter to magnetize a ring magnet, as shown in Fig. 11, so that the poles N and S come one directly over the other. On the first magnet, the poles may be at N and S, in the second at N_1 and S_1, in the third at N_2 and S_2, and in the fourth at N_3 and S_3. It will be seen that such a condition would weaken the field of force very much. Then the length of the field in the iron is only about 180°.

The watch-case receiver used by the Bell Company, which resembles that shown in Fig. 12, has pole pieces about .36 inch wide, .09 inch thick, and .5 inch deep, and brass spools .37 inch wide, .68 inch long, and .31 inch deep. There are two permanent magnets, each about $\frac{7}{16}$ inch wide and $\frac{1}{4}$ inch thick, the diameter of the inside edge being about $1\frac{1}{4}$ inches. Generally, the spools are wound to a resistance of about 60 ohms with No. 38 copper wire.

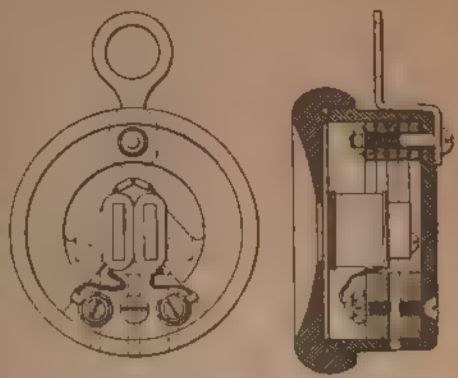


FIG. 12

17. Fig. 12 shows a plan view of a watch-case receiver with cover and diaphragm removed, and a sectional view with those parts in their normal working positions. This is a double-pole receiver, and one of the soft-iron cores attached to each end of the permanent magnet protrudes through each coil. The permanent magnet consists of three parallel pieces. The magnets are circular in form, embracing an arc of about 275°. The terminals of the coils are led to two binding posts, which are wholly contained in the hard rubber case. Fig. 13 shows a Holtzer-

FIG. 13

Cabot watch-case receiver and head-band complete, ready to be placed on the head, so that the receiver shall be held against and cover the ear to exclude sounds coming from external sources.

MULTIPOLAR RECEIVERS

18. Many attempts have been made to improve the general efficiency of the receiver by increasing the number of magnet poles presented to the diaphragm. One of these attempts, due to a European inventor, is shown in Fig. 14. In this receiver, two ring-shaped magnets are placed at right angles to each other, and each terminates in a pole piece projecting through the bottom of a brass cup *c*, which forms the coil chamber. Around each of the four pole pieces is placed a coil similar in form to that used in the ordinary single-pole receivers. As the four pole pieces are arranged in positions corresponding to the corners of a square, the magnetic field that passes through the diaphragm is therefore apparently doubly **strengthened.** The diaphragm is held in place by a screw cap *B* engaging a thread on the cup *c*, the cap carrying a hard rubber earpiece *M*. This is merely an example of many forms of multipolar receivers, and it may be said that they are more expensive to make, more complicated and therefore more difficult to keep in order, heavier and more cumbersome, and therefore less convenient to handle. Moreover,

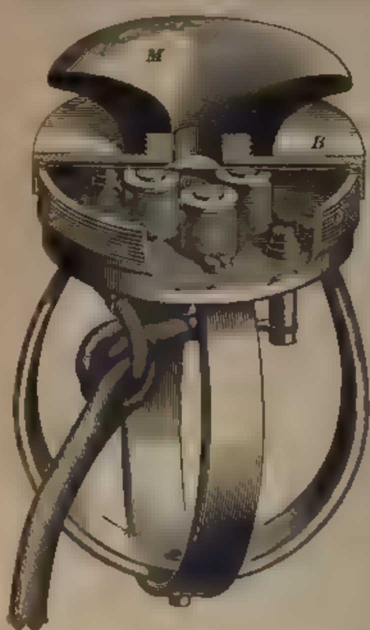


FIG. 14

they do not show any great gain in efficiency over the receivers of the simple bipolar type. They are not used at all in the United States, and but rarely in Europe.

DETAILS OF RECEIVER CONSTRUCTION

19. Magnet Steel.—The most important requisite of the permanent magnet in a receiver, or, in fact, in any telephone apparatus, is that it shall be truly permanent. Many grades of steel are capable of receiving a fair degree of magnetization, but are incapable of retaining their proper strength throughout any considerable length of time. It is very difficult to say what constitutes the best steel for making permanent magnets, but many steel manufacturers are making a special grade for this purpose, which may be purchased under the name of **magnet steel.**

In a steel for permanent magnets for receivers, bells, and generators sulphur and phosphorus are harmful, but there must be a certain amount of manganese and carbon. The following is an analysis of a good magnet steel: Silicon, not less than .1 per cent. nor more than .2 per cent.; sulphur, not more than .05 per cent.; phosphorus, not more than .07 per cent.; manganese, not less than .75 nor more than 1 per cent.; carbon, not less than .56 per cent. nor more than .61 per cent. If it contains less carbon, it will not harden properly, nor will it retain its magnetism for a sufficient length of time. Tungsten steel is about the best material for permanent magnets, because it gives a magnet of about the most uniform and greatest strength and retains its magnetism with considerable tenacity; that is, it has a strong coercive force. However, some claim that ordinary tungsten steel cannot be magnetized as strongly as the magnet steel commonly used. It should be remembered that permanence is more to be desired than mere strength. Tungsten steel is more expensive.

20. The **permanent magnet** for a receiver is usually from 3 to 3½ inches long. Too short a magnet is too easily

demagnetized by the current in the receiver coils, which tends to demagnetize them. Watch-case receivers give considerable trouble for this reason, since the permanent magnet must be made so short.

Permanent magnets for receivers may be heated red hot and shaped in a punch press. After the steel has been worked into the desired shape, it should be heated to a bright cherry red in a rather slow fire, so that the interior and the exterior portions will be at approximately the same temperature. It should then be quickly immersed in cold running water and constantly agitated while cooling. Care should be taken that the tongs do not prevent the water from reaching all parts of the piece at once, as this will prevent some parts of the bar from cooling as rapidly as others, and will frequently produce cracking. A high carbon steel, such as tool steel, will under this treatment become flint-hard; but very often a grade of steel that is capable of producing excellent permanent magnets will, after being thus cooled, be sufficiently soft to allow a file to make a very slight impression on it. The practice, therefore, of judging the grade of a magnet steel by its ability to totally resist the action of a file often leads to the discarding of material admirably suited to the purpose.

21. Magnetizing.—The usual process of magnetizing consists in stroking the bars of hard steel across the poles of a powerful electromagnet. The electromagnet, if designed to be used in producing permanent magnets of various forms, should preferably have removable pole pieces of soft cast iron, so as to accommodate itself more readily to the stroking of the different sizes and shapes of bars. In stroking, the bar to be magnetized should be held on the poles of the electromagnet so that one of its ends rests on the north pole and the other on the south pole; it should then be drawn across the magnet face several times, always keeping it in such position as to close the magnetic circuit between the two poles of the electromagnet. After drawing the bar along the pole pieces six or eight times, lifting the

magnet at the end of each stroke and returning it to the starting point, lay the magnet on its side without removing it from the pole piece and place a keeper across the poles and remove the magnet before turning off the current.

For magnetizing a straight, flat bar, such as is used in the Bell single-pole receiver, the poles of the electromagnet are preferably placed about 3 inches apart, so that, in the case of a bar $4\frac{1}{2}$ inches long, it laps over each pole face about $\frac{3}{4}$ inch. In magnetizing a horseshoe bar, such as in the Ericsson receiver, the poles of the electromagnet are placed about $\frac{3}{4}$ inch apart, so that the two limbs of the **U**-shaped bar rest, in stroking, one on one pole and one on the other.

A process of magnetizing permanent magnets that is adopted by some manufacturing companies, consists in placing the bar of steel to be magnetized within a coil through which a powerful current of electricity is flowing. The magnetic field set up by the current in this case passes, for the most part, through the bar of steel, thus imparting to it a high degree of magnetization. Considerable trouble, however, is experienced, where this process is used, of withdrawing the bar from the coil without destroying a large part of the magnetism set up in it. The demagnetizing effect seems to be a little greater if the current is turned off while the bar remains within the coil than if the magnet is inserted in and withdrawn from the coil without turning off the current.

It is well to arrange the circuit of the electromagnet or magnetizing coil so it can be slowly interrupted, as the repeated turning on of the current tends to magnetize the steel to a higher degree. Tapping the bar while the full current is flowing through the magnetizing coil will also tend to increase its magnetization.

Probably the best results are obtained by the method of stroking across the poles of a very powerful electromagnet, where it is properly carried out.

22. Cores.—The cores forming the pole pieces of receiver magnets should be as thin as is consistent with good mechanical construction, in order to reduce the neutralizing

effect due to eddy currents. They should not be placed too close together, otherwise the magnetic leakage will be excessive. As a rule, however, the winding determines the distance, and the poles may be placed as close together as the spools will allow. The best pole pieces for receivers are about $\frac{1}{16}$ inch thick by $\frac{1}{2}$ inch wide, and only long enough to hold the coil and make a good joint with the permanent magnets. In the case of the bipolar receivers using a flat pole piece, it is customary to stamp the pole pieces from sheet iron rolled to the desired thickness. The object of using separate soft-iron pole pieces, instead of winding the coils directly on the end of the permanent magnets, is that soft iron is much more permeable than is hardened steel, and hence a very much smaller sectional area will allow all the lines of force developed by the permanent magnet to readily pass through the cores. The cores and diaphragm should be magnetized to such a degree that the iron will be most sensitive to small changes in the magnetizing force, due to changes in the current in the coils; the pull exerted by the cores on the diaphragm will then be very sensitive to slight changes in the strength of the current. To attain this object, neither the cores nor the diaphragm should be magnetized very intensely—that is, not too near the saturation point or bend in the magnetization curve. In order to reduce the reluctance between the pole pieces and the permanent magnet, the joining surfaces should be large, very smooth and flat, and very tightly held together.

23. Iron for Cores.—Iron for cores and diaphragms should have a high permeability, low hysteresis, and low retentiveness or coercive force. These desirable properties are possessed by the best quality of soft annealed iron; Swedish or Norway iron has long been considered the ideal material for receiver cores on account of its extreme softness.

If the permeability is high, the sectional area may be smaller than that of the permanent magnet; the average length of one turn of wire in the coil will therefore be less, giving a smaller resistance for a given number of turns;

moreover, the loss from eddy currents and hysteresis in the iron core will be less. If the hysteresis is low, the energy wasted in hysteresis will be small, and the efficiency will be greater. If the coercive force is not small, the magnetization—and hence the pull—will not change readily and the cores may become permanently magnetized.

Norway iron for use in telephone apparatus should be about 99.9 per cent. chemically pure iron; a variation of .01 or .02 per cent. of certain metalloids, such as sulphur, phosphorus, and silicon, is sufficient to make it entirely unfit for telephone instruments. By the chemical analyses of a great many samples that were afterwards given practical tests, it has been proved that the results obtained from the chemical analysis of a sample of iron will indicate the relative value for the purpose intended. Hence, the manufacturer who desires to turn out a uniform product should have the same quality of raw material in it, which may be determined only by a chemical analysis of each lot before it is sold.

The hardening quality of Norway iron is due to carbon and manganese. The amount of carbon present should not exceed .1 per cent., and the manganese should not exceed .08 per cent.; some Norway iron contains no manganese. It is impossible to entirely remove all the sulphur and phosphorus, both of which are injurious; hence, it is necessary to make Norway iron from ores containing as little as possible of these two elements. The amount of sulphur should be less than .01 per cent. and the phosphorus should not exceed .03 per cent. Another element, silicon, which is also present in iron, should not exceed .05 per cent.

The following is a sample analysis of a good grade of Norway iron used for the cores of receivers: silicon, .005 per cent.; carbon, .01 per cent. There should be practically no sulphur or phosphorus and little or no manganese in such an iron.

24. Hadfield Iron.—Robert A. Hadfield, of Sheffield, England, claims to have produced an improved magnetically

soft iron having especially high permeability, high electrical resistance, and low hysteresis. These qualities are produced by alloying pure Swedish or other suitable pure iron with silicon, or aluminum, or phosphorus, or with two or three of these elements. The iron is melted in a common crucible or electrically, along with the silicon, or aluminum ($2\frac{1}{4}$ per cent.), or phosphorus. Any steel process by which the carbon and silicon are removed from the iron may be used, adding to such an iron the elements desired. A good alloy actually manufactured contained 2.75 per cent. silicon, .07 per cent. carbon, .08 per cent. manganese, .03 per cent. sulphur, and .03 per cent. phosphorus. It is important to keep the percentage of carbon and manganese as low as possible—say, each under .12 per cent. This alloy can be still further improved by a treatment involving alternate heating and cooling, and should be carried out about as follows: The material is first heated to between about 900° and 1,100° C., and allowed to cool quickly. Then it is reheated to between about 700° and 850° C.—that is, to a temperature lower than the one obtained during the first heating—and then allowed to cool very slowly. In practice the cooling has been extended to last several days. Either or both of these treatments may be frequently repeated, but for the best results it is of great importance to use as near as possible the exact temperatures mentioned, and careful readings of the temperature by a pyrometer should be taken for this purpose. This improved alloy is said to have a higher magnetic permeability and a lower hysteresis than any magnetic material for which there are tests, including the purest iron. Iron made in this manner should be suitable for receiver cores and diaphragms, armature cores of magneto-generators, motors or dynamos, for the iron-wire cores of induction and repeating coils, and wherever a good quality of soft magnetic iron is required.

25. In annealing iron for telephone apparatus, the following is an excellent process, according to W. A. Taylor in the Electrical Review: The parts to be annealed are placed

in an annealing pot and packed carefully in iron filings or turnings so that none of the parts touch the sides of the pot. The cover is then sealed on with fireclay and the whole placed in the annealing furnace. The pot is usually made of cast iron, though sometimes of boiler iron. The pot and contents are heated to an almost white heat and kept that way for 10 hours, when the whole furnace and contents are allowed to cool slowly. If the pots are large—say, about 1 cubic foot or more—they may be withdrawn from the furnace and allowed to cool on the floor. When entirely cool, the articles may be taken out. If the directions are followed carefully, the articles will be very soft and almost white. If there is any scale on them the annealing has not been properly done; neither should annealed pieces be blue. The iron turnings or filings, in which the pieces to be annealed are packed, should be free from wrought iron or very low carbon steel. Any material amount of carbon will case-harden the articles.

26. Diaphragm.—The diameter, thickness, and distance of the diaphragm from the pole pieces should be carefully considered. The diaphragms generally used are about $2\frac{1}{8}$ to $2\frac{1}{4}$ inches in diameter, with an available vibrating portion from $1\frac{7}{8}$ to 2 inches. The thickness is usually about .01 inch. The distance from the pole pieces varies widely in different makes—from $\frac{1}{32}$ down to $\frac{1}{64}$ inch. A good way is to make the distance as close as possible and still not have the diaphragm touch the pole pieces. At the greatest amplitude of vibration this distance should be about $\frac{1}{64}$ inch, with a diaphragm of the above dimensions. Should the diaphragm be made larger in diameter, the thickness should also be increased. The matter of dimensions is determined by testing a large number, choosing the best.

The stronger the magnet of a receiver, the thicker should be the diaphragm in order to avoid magnetic saturation. The strongest magnet, when new, does not necessarily give the best results during the whole life of the receiver, because the diaphragm may not be properly designed, and, more-

over, the magnet may deteriorate in strength so much as to soon become less efficient than a receiver with a thinner diaphragm and a weaker magnet when new, but which retains its magnetism more permanently.

Iron for diaphragms should possess high permeability, small coercive force, and little hysteresis. The best Norway or annealed charcoal iron and sheet steel seem to be superior to ferrotype iron in permeability at low and medium magnetized forces. Furthermore, a diaphragm should never be too highly magnetized, because it is not then as sensitive to slight changes in the current in the coils. Sheet steel seems to be fully as good, if not better, than annealed charcoal iron, and both have less hysteresis than ferrotype iron.

27. Spools.—The spool for confining the wire within its proper limits was usually, in the case of single-pole receivers, turned from boxwood or some similar hard wood, and was slipped on the pole piece, as shown in Fig. 1. The wires leading from the coil were brought out through small holes in the lower side of the spool. In the case of bipolar receivers having flat coils, it is customary to form the spool as an integral part of the core itself, as shown in Fig. 15. This is done by punching the heads a, a from sheet brass or German silver and forcing them on the pole pieces to the positions desired. Frequently, as an additional precaution, they are soldered in place on the pole pieces, or, instead of this, are secured by means of prick-punch marks at points along the line where the head joins the core. After the spool is properly formed, great care must be taken to insulate it in such manner that it will be impossible for the wire used in winding the coil to become short-circuited or crossed on the core. To accomplish this, the best

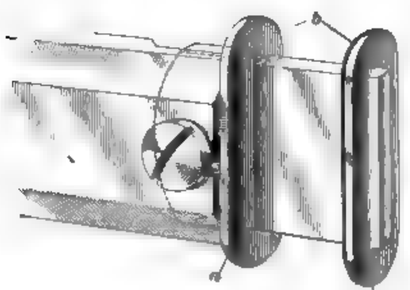


FIG. 15

practice is to place two, thin, fiber washers *b* on the core between the two heads; these are then placed, one in contact with each head, as shown in Fig. 15, and serve as effective insulators between the wire and the heads. A thin layer of paper should be wrapped around the pole piece between the heads, in order to keep the wire from touching the pole piece. The terminals of the wire from the coils should never be brought out through holes in metal heads, as this practice has proved one of the most prolific causes of trouble in receiving instruments.

28. Coils.—After the spool has been formed and properly insulated, it is placed in a suitable chuck on a winding machine and wound with the desired length of silk-covered copper wire.

A winding space $\frac{3}{8}$ inch in width will allow about 1,000 turns of No. 36 silk-covered magnet wire to be wound to a depth of $\frac{1}{8}$ inch. That will make 2,000 turns for both coils and give a resistance of about 100 ohms. Single-covered wire is used in preference to the double-covered, as its insulation is ample, and a greater amount of wire may be placed in a given space. The resistance of single-pole receivers is usually about 75 ohms, and the size of wire either No. 36 or No. 38 B. & S. gauge. In double-pole receivers, the resistance of each coil is, as a rule, 30 to 50 ohms, making their joint resistance 60 to 100 ohms. The same sizes of wire as given above are in common use. For some central-energy and house systems the receivers are wound to a much lower resistance than those specified, the size of wire being correspondingly larger. The Bell Company frequently wind both their single- and double-pole receivers with two parallel No. 38 wires, the wires being wound on side by side and connected in parallel.

It is always a good rule to use as coarse wire as possible for the winding, as there is less danger of a burn-out from any cause. That means wind the receiver as low as possible without sacrificing its efficiency. Furthermore, to reduce breaking and repairs, the last few turns on a spool

should be made with much larger wire; and still larger wire, No. 18 or 20, should be used between the coils and the binding, or terminal, screws. The coils for both single- and double-pole instruments should be placed over the core as near the diaphragm end of it as possible, where they will produce the greatest possible change in the number of lines of force passing out of the iron core into the air gap and diaphragm.

29. Shells.—The advisability of so designing the receivers as to avoid the possibility of the unequal contraction and expansion of the shells and magnets causing the distance between the diaphragm and pole piece to vary, has been referred to in considering the various types of commercial receivers. The practice of making the receiver shell partially of brass, with a view of remedying this evil, is to be commended, although it may be said that hard-rubber shells, when a proper method of supporting the magnet is used, are thoroughly reliable and in every way satisfactory.

30. Substitutes for Hard Rubber.—The shell should, preferably, be made of the best grade of hard rubber. However, many manufacturing concerns use, in the place of hard rubber, substitutes generally called composition. Formerly these substitutes were brittle, and many of them gradually warped or otherwise changed their shape during hot weather, thus permanently spoiling the adjustment of the receiver. Again, many of these substances possessed the quality of slowly absorbing moisture, which rendered their insulating qualities poor, besides gradually destroying the black finish of the surface. The quality of composition has been greatly improved in the last few years, and comparatively few receiver shells are now made of good hard rubber, on account of its high price and the severe competition between manufacturers of receivers. There is still room for improvement, as it is not yet as strong, durable, or handsome as hard rubber.

31. To Repolish Receiver Shells.—Old receiver shells may be readily repolished, if a lathe is available, as follows:

With 000 sandpaper remove all scratches, then put the rear end in the lathe chuck with the dead center against the ear-piece opening. With the lathe running at a speed not so high as to burn the shell, apply pulverized pumice stone and water with a brush or heavy rag; wash off the pumice stone and polish with whiting and a soft brush. By applying oil and lampblack or rotten stone, a very high polish may be obtained.

32. Binding Posts.—The question of properly securing the binding posts and also making the electrical connections to them is a simple one, but when improperly attended to always produces much trouble. One of the most approved binding posts and the method of attaching it to the shell is shown in Fig. 16. In this, *S* is the stem of the post provided with a shoulder *s* adapted to abut against the shell; the inside stem extends through the shell and is screw-threaded to receive a nut for securing it in place. A small hole is preferably drilled in the inner end of this stem for the reception of the heavy leading-in wire, which is soldered in place after being inserted. *C* is a collar adapted to slide loosely on the upper part of the stem, and *N* is a thumb nut adapted to press the collar *C* firmly against the cord terminal inserted into the hole *O* through the main stem. Great attention should be paid to preventing the binding posts from twisting in their places, as this action often causes a short circuit by allowing one terminal of the receiver cord to come in contact with the other. The twisting may be prevented by the insertion of small dowel-pins in the shoulders on the stem of the post, which, when the post is forced into place, enter the shell. Another way of preventing this short-circuiting by the twisting of posts is by use of a small hard-rubber block

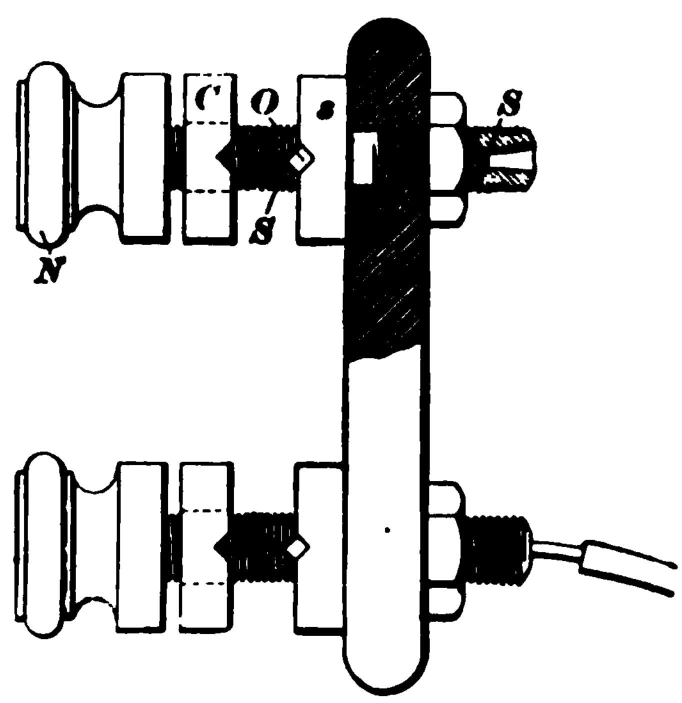


FIG. 16

attached to the shell between the two binding posts, such a block being shown at *B* in Fig. 4.

It is well to leave the inner ends of the stem of the post long enough to project a slight distance beyond the hard rubber, so that the hard rubber itself will not be unduly heated in soldering the leading-in wire in place. Failure to provide against this is the cause of many loose binding posts, for when the shell is heated, it softens and thus yields to the pressure exerted on it by the inner nut. The use of binding posts on the outside of receivers has been discontinued by many manufacturers.

33. Receiver Cords.—In order to allow for the handling of the receiver, it is necessary to connect it with the body of the telephone by a flexible conductor that permits the free movement of the receiver, and at the same time maintains electrical connection between its terminals and the interior circuits of the telephone box. The cord must necessarily contain two conductors, one leading to each terminal of the receiver. These conductors are usually formed of twisted or braided tinsel strands provided with an insulating covering of silk or cotton, and afterwards laid together and covered with a braiding of worsted or silk, binding the two conductors together. As a precaution against mechanical injury to the conductors, it is not uncommon, after the first layer of insulation has been put on, to incase each conductor in a spiral wrapping of spring brass wire. This wire forms no part of the conductor, but serves as a flexible mechanical protector for the conductor within. The two armored conductors are afterwards braided over in the manner before described. It is best to bind in with the conductors a cord that may be designed to relieve the conductors of all the strain by securely tying it to firm supports at each end. Or, the outer braid may be made to form a cord, with or without special terminal pieces, at each end.

A good receiver cord is made as follows: The conductor is composed of a large number of tinsel strands with which a few fine copper wires are woven in order to impart a greater

strength. About this conductor is wrapped a layer of floss silk; this is preferably put on as a wrapping instead of as a braiding, because the former serves to bind the fine ends of the conductors closely together, thus affording them no chance to project through the insulation and form a short circuit with the companion conductor. Over this layer of silk is placed a braid of linen or hard cotton, outside of which is placed the armor of spring brass wire. The two conductors are then laid together and served with a braiding of colored worsted, thus giving them the well-known appearance.

The worsted receiver cord, made by the Kellogg Switchboard and Supply Company, consists of twenty-seven strands of tinsel covered with an inner braiding of cotton and an outer braiding of worsted. One conductor has a black worsted braiding, and the other a red-and-black worsted braiding. Both conductors are enclosed in a dark-red-and-black worsted braiding provided with stay-cords at each end to take the weight of the receiver off the cords. Both conductors are provided with proper terminals at each end. Their green-silk receiver cords consist of twenty-seven strands of tinsel with one white-cotton and one green-cotton braiding, the two conductors being covered with a green-silk braiding reenforced at both ends and provided with stay-cords. One conductor has a red tracing thread in the braiding.

34. Cord Tips.—The most difficult matter in the construction of receiver cords is to attach the tips to the conductors so that the strain due to the handling of the receiver will not fall on the conductor itself, but on the braiding, and at the same time to provide against breakage at the juncture of the conductor and the tip, due to the sharp bending that is likely to occur at that point. One of the best methods of overcoming this difficulty is shown in Fig. 17. *A* is a pointed piece of wire forming the tip of the cord. The pointed end of this is inserted in the conductor of the cord, and passed out through the braid, and bent over on

itself so as to form a hook, as shown. This hook is then closed by pressure with a pair of pincers and the end wrapped with thread, after which the thimble *B* is slipped in place over the hook and securely soldered. This thimble is of such size as to fit closely over the external portion of the cord, therefore rendering it impossible to pull off the tip without tearing through the external braiding, which in itself

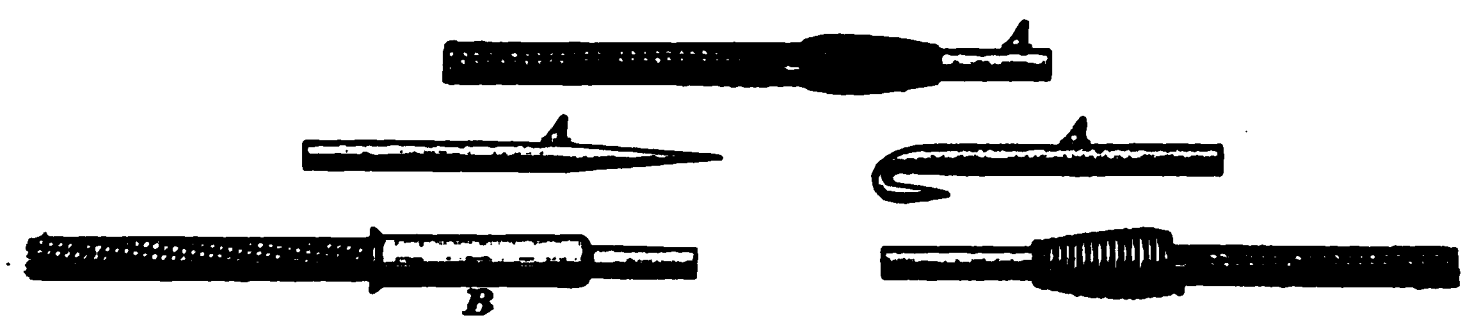


FIG. 17

possesses considerable strength. Instead of the thimble *B* a wrapping of wire may be used, as shown in the lower right-hand view in Fig. 17.

35. Combination Cord Clamp.—The cords supplied regularly with the Dean Electric Company's receiver, which resembles the receiver made by the American Electric Telephone Company, has metal tips, as shown at *B*, Fig. 17, on

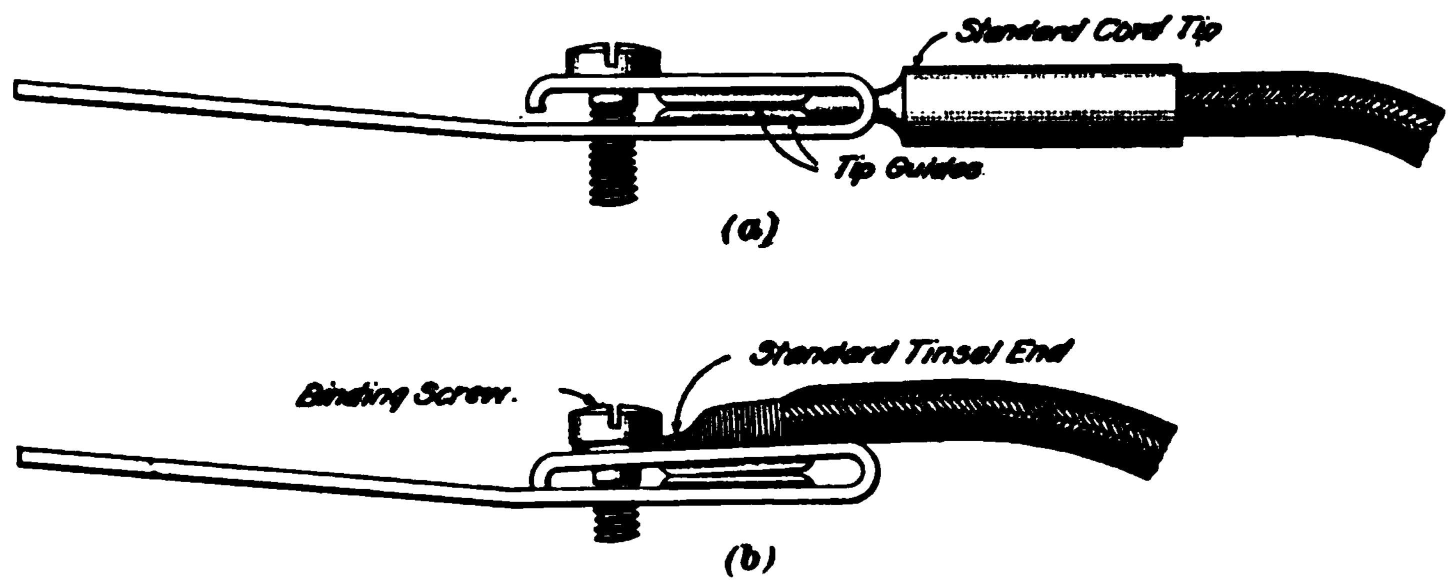


FIG. 18

all four ends. The cord is fastened to the magnet yoke by an extension of the outer braiding; the other end of the cord has a similar extension of the braiding, but this is provided with a metal eye, by means of which the cord is anchored to one of the binding posts to which one tip is connected. Combination binding clamps, shown in Fig. 18, are fastened on opposite sides of the receiver magnets within the shell.

These binding clamps are so constructed that they will tightly grip any standard cord tip, like that shown at *B* in Fig. 17, in the manner shown at Fig. 18 (*a*), or will securely clamp under the head of the binding screw the end of any ordinary cord, as shown at Fig. 18 (*b*). The binding clamps have ends that project into the receiver cup containing the coils and to which the ends of the coils are soldered.

TESTING RECEIVERS

36. It is very important that a telephone receiver should respond to currents of very high frequency, for the high-frequency currents are the most weakened in transmission over lines, especially long lines and cables; therefore, it is necessary that they be not further weakened in their reproduction by the receiver into sound; otherwise, the articulation will be still more muffled. According to Mr. W. W. Dean, in the American Telephone Journal, experience seems to show that a telephone receiver that will detect very weak currents of 1,000 cycles per second will also produce a sufficiently loud sound when strong currents of a very much lower period pass through it.

The pull of the permanent magnets on the diaphragm of a receiver causes the diaphragm to be normally deflected out of a straight line toward the magnets. In the average receiver, this deflection from a straight line is about .002 inch, depending, of course, on the thickness and diameter of the diaphragm, strength of the permanent magnets, and the distance between the pole pieces and the clamping surface on which the edge of the diaphragm rests. The resistance of the windings of the telephone receiver can suffer wide variations without appreciably affecting the volume of transmission, because it forms a very small part of the total resistance of the circuit in which it is connected.

37. Dean Method.—In making comparative tests of receivers of different dimensions and makes, Mr. Dean says the method shown in Fig. 19 is an extremely valuable one.

The toothed wheel W is made of cast iron and is mounted directly on the shaft of a small direct-current fan motor. Rigidly mounted in front of this toothed wheel are the magnets and bobbins of an ordinary bipolar telephone receiver. When the toothed wheel W revolves in front of the cores, an alternating current is generated in the coils; in other words, this is simply a small alternating-current generator. In the machines that Mr. Dean has constantly used for a number of years, the wheel W has twenty teeth, and he has been able to revolve it at the rate of 3,000 revolutions

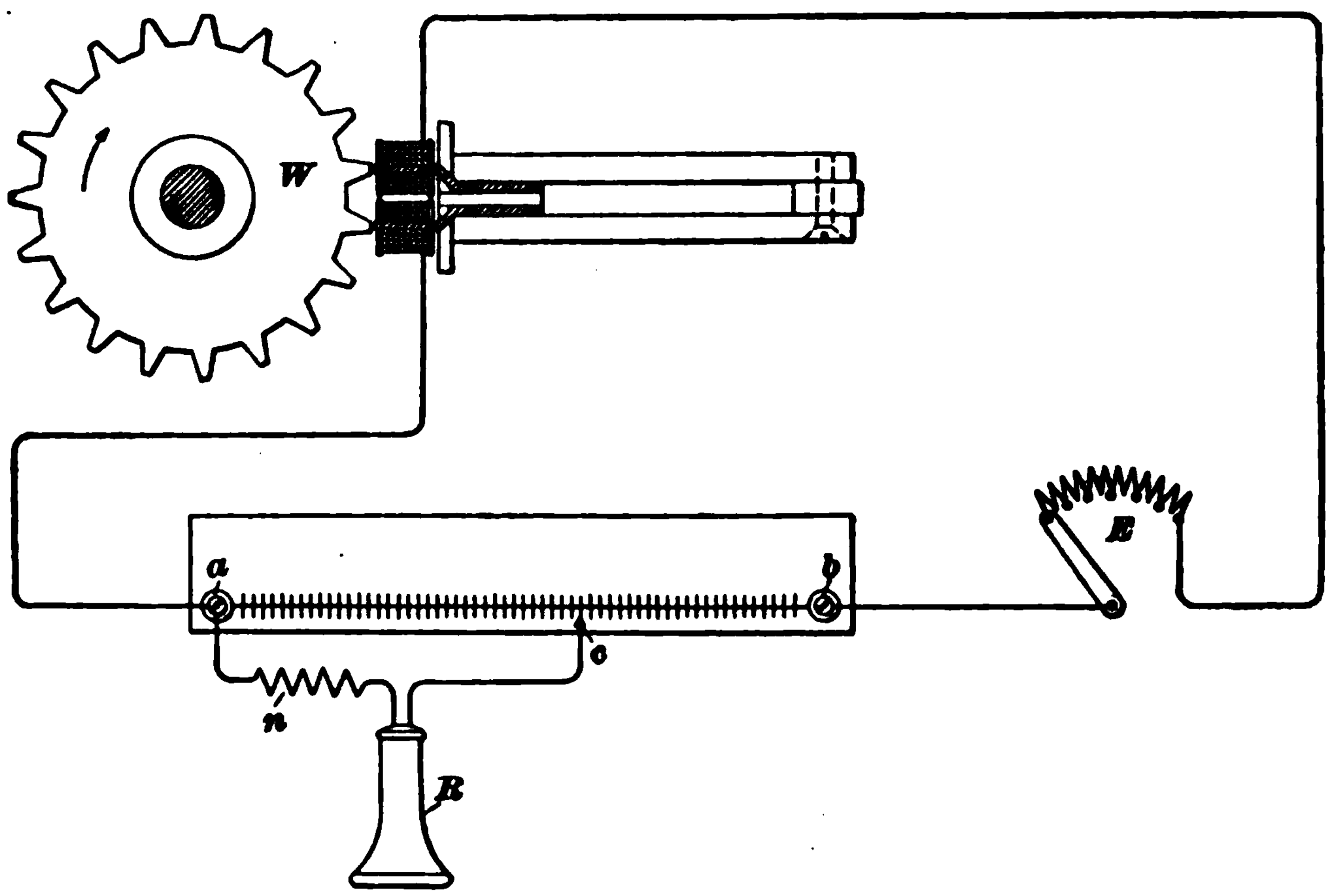


FIG. 19

per minute, so that an alternating current of 1,000 cycles per second is generated in the receiver coils.

When this current is passed through a second telephone receiver, a loud pure tone of extremely high pitch is heard. Connect the terminals of this small alternating-current generator through an adjustable rheostat E to the terminals of a slide wire $a\,b$ that is 1 meter long and is divided into 1,000 parts, or millimeters. Adjust the potential difference between the points a and b to any desired amount by means of the rheostat E. In comparing two receivers, the method is as follows: Connect one terminal of the receiver through

a very high resistance *n* to the point *a* of the slide wire, and the other terminal of the receiver to the sliding connection *c*. Move the point *c* along the slide wire until the sound of the alternator is just audible in the receiver, and then note the reading on the scale. Say, for instance, that the reading is 750 millimeters. Next, the receiver that is to be compared with the first one is substituted for receiver *R*, and then, by sliding the contact *c*, the point is found at which the alternating current is just audible in this receiver, and a second reading is made, say, for example, 650 millimeters. It is fair to suppose now that the relative values of these two receivers are represented by 750 and 650. It is necessary in making this test to place the apparatus in a sound-proof booth. Otherwise, it is impossible to accurately determine the point at which sound is first audible, and to be of value the experiment must be accurately performed.

38. Taylor Method.—A very simple way to compare the sensitiveness, or strength, of receivers, given by W. A. Taylor in the Electrical Review, is as follows: Remove the cap and diaphragm from a receiver and fasten it solidly into the tool post of a lathe. Then between the lathe centers place a gear-wheel such as is generally used about a lathe, say about 6 inches in diameter. Bring the receiver poles close to the teeth of the gear and then start the lathe on high speed. From this receiver, run a line to the receiver to be tested; on listening to this latter receiver, a loud musical hum will be heard. Now run the tool post back from the gear until a point is reached where the hum becomes inaudible. In place of the receiver being tested substitute another, and see if the hum can be heard with the tool post as far or farther than before. If the tool-post screw has an index attachment, it will facilitate the marking of the distances. This method will not give exactly the proportional relation between receivers, as the magnetic field reduces, not directly as the distance, but more nearly proportional to the square of the distance between the pole pieces and the gear-teeth. This is, however, a

simple test for loudness and sensitiveness, but will tell absolutely nothing about articulation. The latter is, of course, of the most importance and can be judged only from a test of words spoken before a transmitter known to be very superior. Such tests will be considered in connection with induction coils. Almost any receiver will articulate plainly on a line where the voice currents are weak, but the severe tests come from transmission that is excessively strong.

RECEIVER TROUBLES

39. Receiver troubles are mostly due to bad adjustment, dented or bent diaphragm, broken wire, or weak magnets. The magnet should hold up 8 ounces of iron. It will be frequently found that subscribers, or their employes, have been tampering with the diaphragm through the small aperture, indicated by the indentations caused by a pencil; in this case the only thing to do is to change the diaphragm and warn the party.

The adjustment of receiver magnets is different in each style. A good way to test the adjustment is to lay a long pencil across the ear piece at the end of the magnets, with the cap and diaphragm off and adjust the magnet so that it is $\frac{1}{32}$ inch clear of the pencil. A part of the receiver is the cord attaching it to the instrument, and this frequently causes trouble by being broken or having the tinsel worn; in which case, an irritating intermittent trouble presents itself, and must be patiently looked for and repaired; it is generally caused by the tinsel being worn and making poor contact; it can, as a rule, be found by twisting or pulling the cord while holding the receiver to the ear. The interior of the receiver, especially between the cores and the diaphragm, should be kept clear of dust.

Sometimes it is necessary to take the receiver cap off in order to investigate trouble, and it may be found that the cap cannot be turned. Several quick raps with a piece of soft wood on the edge of the cap will generally loosen it; if not, heat the cap and it will be loosened by expansion.

TELEPHONE TRANSMITTERS

MAGNETO-TRANSMITTERS

1. While the magneto-telephone is extensively used as a receiver it is no longer used as a transmitter even on short lines. Moreover, the microphone transmitter has proved so much superior for use on short as well as long lines that there is little or no demand for **magneto-transmitters.** While the patents on microphone transmitters were in force, magneto-transmitters were made; but they are no longer manufactured or used in telephone-exchange systems in the United States.

The magneto-transmitter is seemingly the ideal instrument for generating currents corresponding to the vibrations set up by the voice. They require no battery power, and when properly constructed and adjusted, need no attention whatever. They articulate exceedingly well, and their only drawback is in their lack of power, which so far has proved an insurmountable difficulty. It is usually necessary to talk very loud or shout into them. They may be used where it is impossible or very inconvenient to use a battery for a microphone transmitter. Watch-case receivers are frequently used as transmitters in linemen's testing sets, which are usually made as light and compact as possible. A magneto-transmitter should have a powerful magnetic field, this means one or more powerful permanent magnets and a diaphragm correspondingly thicker and larger in diameter. At one time the Stromberg-Carlson Telephone Manufacturing Company made a magneto-transmitter, using large permanent magnets that served also for the magneto-generator.

MICROPHONE TRANSMITTERS

CLASSIFICATION

2. The various forms of commercial **microphone transmitters** will be considered under three separate heads, the classification being substantially the same as that adopted by the United States Patent Office.

3. Single-Contact Microphones.—These are instruments where but a single pair of contacts is used as the variable resistance medium.

4. Multiple-Electrode Microphones.—Soon after the invention of the microphone, many attempts to improve its efficiency were made by increasing the number of pairs of contacts through which the current passes. This class is well termed **multiple electrode.** In some of these, the circuit is so arranged as to include the various contacts in multiple or parallel, in others so as to include them in series, and in others in a combination of the two, that is, both in series and in parallel.

5. Granular Microphones.—These are in reality a particular form of the multiple-electrode type, but are of such distinct construction as to warrant putting them in a separate class. Nearly all good commercial transmitters at the present time use granular carbon as the variable resistance medium, this idea, it will be remembered, having been conceived by Hunning.

SINGLE-CONTACT MICROPHONE TRANSMITTERS

6. The Blake Transmitter.—One of the early transmitters was that devised by Francis Blake, and is shown in Fig. 1. It was extensively and constantly used in the United States for about 20 years, not because it was better or even as good as many others, but because it was fairly efficient and required little battery power.

Around the edge of the diaphragm is stretched a soft-rubber band, serving to insulate it from the iron frame and to allow it freedom in vibrating. Two damping springs V_1, V_2, tipped with rubber, rest lightly on the diaphragm D, to prevent the continued vibration of the diaphragm at its own particular rate after the sound vibrations cease to control its movements. Thus it is brought to rest immediately, and is

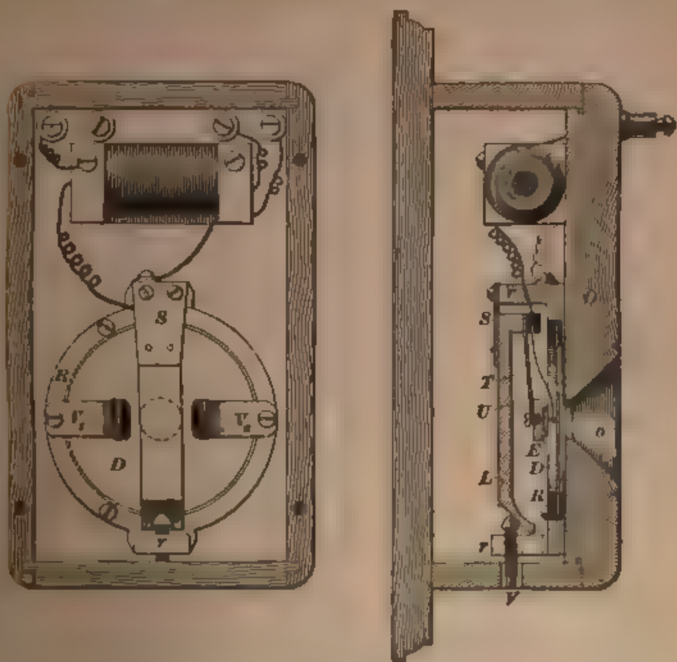


FIG. 1

ready to respond to the following sound waves without interfering with them by its own natural vibrations, which would cause indistinctness in the sound given out by the receiver. They also prevent too great an amplitude of vibration of the diaphragm.

Flexibly mounted on the upper lug r by the spring S is a lever L, on which is mounted a spring U, which carries the back electrode E, formed of a hard carbon button, set into a rather heavy brass button. This carbon electrode is in

electrical contact with the lever *L*. On an insulating block also mounted on the lever *L*, and thus insulated at this place from both it and the spring *U*, is attached a lighter spring *T* carrying at its lower end a small piece of platinum, which is held between the diaphragm and the carbon button. The normal set of the spring *T* is toward the button and away from the diaphragm, but the pressure of the spring *U*, which is much the stronger of the two, overcomes this and keeps the platinum pressed against the diaphragm. This prevents any possible parting of the carbon and platinum electrodes, which would cause a serious disturbance at the receiver. The frame *R*, which is in electrical connection with the back electrode, forms one terminal of this instrument, while the spring *T* forms the other terminal. The adjustment of pressure between the electrodes is accomplished by turning the screw *V*, which moves the lever *L* backwards or forwards in an obvious manner. Many experiments were performed trying various substances as electrodes, and it was determined that, of all easily obtainable materials, one electrode of carbon and the other of platinum gave the best results. When both electrodes were made of carbon, they seemed less apt to part and thus produce a click in the receiver due to a break in the microphone contact than when one electrode was carbon and the other of platinum, but the latter combination gave a better quality to the reproduced sound. The carbon should be hard and well polished, so as to avoid wear at its contact with the platinum. The brass button into which the carbon button is set is made heavy, so as to have considerable inertia. A light electrode, no matter how the strength of the spring is varied or adjusted, does not give nearly as good results. The inertia of the heavy electrode tends to prevent its velocity increasing or decreasing as rapidly as the velocity of the platinum electrode, and therefore there is a greater change in the pressure than would be the case where a constant pressure of a spring only was utilized. This transmitter, when in good adjustment, articulates well and transmits the quality of the voice very well. It is not very powerful, however, and will not stand more than one

cell of battery; more cells will cause the instrument to give forth a singing or sputtering sound.

7. The production of the humming sound caused by too light an adjustment between the electrodes or by too great a battery power is due to what is known as **Trevelyan's effect.** When the current passes through the point of contact it causes a heating, and therefore an expansion, of the particles in the contact. This forces the electrodes farther away and thereby increases the resistance through them; this diminishes the current and therefore lowers the temperature, thus allowing the electrodes to come closer together again. This in turn diminishes the resistance, causes an increase in the flow of current, and produces another heating effect, so that under a particular adjustment these effects take place periodically and cause the humming sound referred to.

The average resistance of this transmitter is about 5 ohms. It is not satisfactory for long-distance transmission and is easily put out of adjustment. It works best with about .13 ampere and when the speaker's mouth is about 4 inches from the mouthpiece.

MULTIPLE-ELECTRODE TRANSMITTERS

8. Carbon-Ball Transmitter.—All carbon-ball transmitters are modifications of the Hughes microphone. The form shown in Fig. 2 is a good example of a transmitter belonging to the multiple-electrode class. A vibrating diaphragm *D*, in this case of carbon, is clamped between a hard-rubber cup *C* and a metal cap *B*, the latter carrying a mouthpiece *M*. Secured by a screw *a* is the back carbon block *A*, having a number of cylindrical holes bored in its front surface. Within each of these holes is a carbon ball which rests loosely against the diaphragm and against the back block, and therefore completes the circuit between the two. In electrical contact with the diaphragm is a metal cap *B* to which is secured a wire *b* for making connection with one side of the local circuit. The screw *a* makes contact with the carbon block, and the wire *a'* leading from it

connects with the other side of the local circuit. This form of transmitter is capable of giving very fair results, but has been almost entirely superseded by those of the granular-carbon type, which will be described later. This transmitter has the advantage of requiring little attention, if properly made, but a loud sound often causes the contact between the

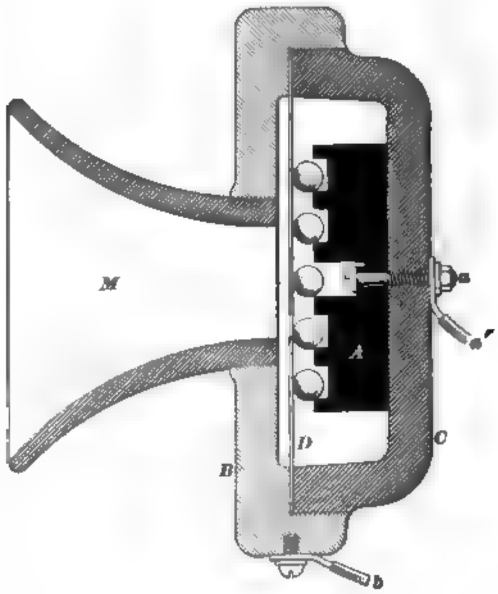


FIG. 2

diaphragm and the balls to break entirely, thus producing loud and unpleasant rasping sounds in the receiver.

9. The Turnbull Transmitter.—This is another form of multiple-electrode instrument now very little used, but interesting and instructive as being one of the most promising instruments in the multiple-electrode class. It is shown in Fig. 3, in which *D* represents the vibrating diaphragm, usually of thin, dry wood. Secured across the upper portion of the diaphragm is a horizontal rod on which a number of cylindrical carbon pendants *P* are pivoted. The lower ends of these pendants rest against a horizontal

carbon rod about opposite the horizontal center line of the diaphragm. The circuit may be traced from the upper pivot rod, which is of conducting material, or carbon, through the several pendants, in multiple, to the lower carbon rod. When the diaphragm vibrates, the pressure on the various contacts varies, and each produces its own microphonic effect, all, however, supposedly acting in unison.

FIG. 3

This transmitter proved exceedingly sensitive, but was open to the same objection as the carbon-ball instrument, of breaking contact on being actuated by loud sounds. Instruments of this and similar types embodying carbon pencils resting in various manners against blocks of carbon have been used to a comparatively slight extent in this country, but have met with better favor in Europe, where they may still be found.

GRANULAR TRANSMITTERS

10. The Ericsson Transmitter.—This instrument, which is shown in Fig. 4, is manufactured in Sweden and imported into this country as a companion piece to the Ericsson bipolar receiver. It is an excellent transmitter, producing a tone almost perfect in quality, and although not quite so powerful as some other instruments, is sufficiently so to be used on very long lines. The diaphragm D, made of ferrotype metal, is held in its position against the forward portion of the casing by two pairs of light springs s bearing against four points on its rear surface. To the rear of the diaphragm is riveted a thin sheet-metal electrode E, which is

gold plated, in order to prevent corrosion and to secure clean contact. The back electrode C is a cylindrical carbon block having circular grooves in its front face. Around the cylindrical edge of this block is wound a layer of cloth c in such a manner as to project about $\frac{1}{8}$ inch beyond the front face of the block. This projecting edge of cloth is frayed so as to press lightly against the edges of the front electrode without interfering seriously with its vibrations. The chamber enclosed by this cloth is filled with granular carbon. The cloth c serves not only to confine the granular carbon within its chamber, but as a damper to prevent too violent a motion of the diaphragm. An additional damper is formed by the

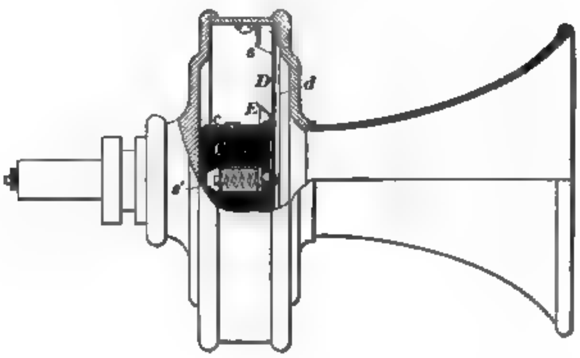


FIG. 4

coiled spring s' in the central cavity in the back block, which presses a small tuft of cotton against the center of the front electrode. In order to prevent moisture from the breath from entering the instrument, a thin diaphragm d of oiled silk is placed in front of the diaphragm D and forms a moisture-proof packing between the front edges of this diaphragm and the metal casing that encloses the working parts of the transmitter. This silk diaphragm has been found not to affect appreciably the transmitting qualities of the instrument. The granular carbon is rough, but very uniform and rather fine in size. For central-energy systems, this transmitter is designed to use about .025 ampere.

11. The DeVeau Transmitter.—The DeVeau transmitter is shown in Fig. 5. One corrugated carbon disk *c* is cemented to a thin brass disk *a* and the two are fastened to the diaphragm, which is insulated from the frame by a rubber band around its edge. A fine wire has one end soldered to the disk *a* and the other end to a brass terminal piece mounted on the hard-rubber piece *f*. Similar carbon and brass disks *c*, *b* are fastened to the round brass rod *i*, which is supported by a bridge piece *n* fastened to the substantial frame that also forms the other terminal of the instrument. There is a setscrew by which *i* may be held firmly in place when once adjusted. Around the two carbon disks is a piece of chamois skin that is held in place by two fine binding wires, one in each groove formed between the edges of the carbon and brass disks, the chamois skin being loose enough to put no strain on the carbon electrodes. The space between the carbons is partly filled with very hard rough carbon of uniform size. The brass disks *a*, *b* are $\frac{1}{32}$ inch thick and the carbon disks *c*, *c* $\frac{1}{8}$ inch thick; both are $\frac{3}{4}$ inch in diameter. The diaphragm is tinned on the inside and japanned on the outside, and is held in place by two rubber-tipped springs, one of which bears against the rubber band around the edge of the diaphragm and the other against the diaphragm, but has a small piece of soft felt between the rubber on its end and the diaphragm. This transmitter, for use in house systems, has a resistance that varies from about 25 to 85 ohms when measured by means of a Wheatstone bridge.

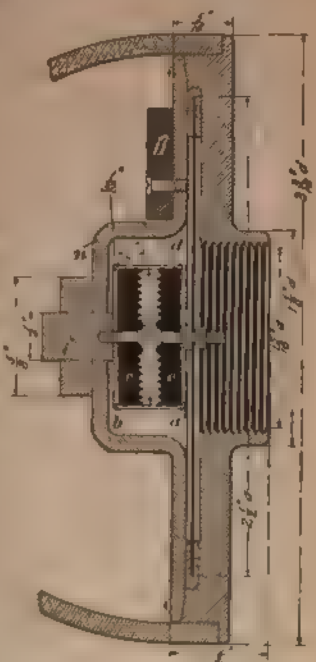


FIG. 5

Although instruments of this type are capable of producing good transmission, the center of the diaphragm is rather heavily weighted. The electrode, with its screw, nut, and washer holding the front electrode away from the diaphragm, usually possesses considerable weight, and therefore inertia, which prevents the diaphragm from moving with as great a freedom as it otherwise would. However, this particular instrument operates in a very satisfactory manner.

SOLID-BACK TRANSMITTERS

12. Most of the granular-carbon transmitters now made are called **solid-back transmitters** because the back electrode is rigidly supported by the frame of the instrument. The White transmitter, used by the licensees of the American Bell Telephone Company, and the transmitters made by the Kellogg Switchboard and Supply and the Dean Electric Companies are solid-back instruments of very similar and excellent construction. The Ericsson and DeVeau are also solid-back transmitters.

13. The **White transmitter,** which was designed by Mr. Anthony C. White, is shown in Fig. 6. On a rather heavy brass casting H, turned to the form shown, all the working parts of the instrument are mounted. D is a vibrating diaphragm of aluminum .022 inch in thickness and $2\frac{1}{2}$ inches in diameter. Around the edge of this diaphragm is stretched a flat rubber band p, $\frac{3}{4}$ inch wide and of sufficient elasticity to allow it to clasp the edges of both sides of the diaphragm, as shown in the sectional views. The diaphragm is held in its seat on the inner surface of the casting H by two damping springs s, s' secured to the edge of the casting H at diametrically opposite points by screws; and each of these springs is tipped with a piece of soft-rubber tubing s'', so that the springs will not come in metallic contact with the diaphragm. The tip of the spring s is also provided on its under side with a small felt cushion s'''. The spring s bears against the diaphragm at a point nearly half way

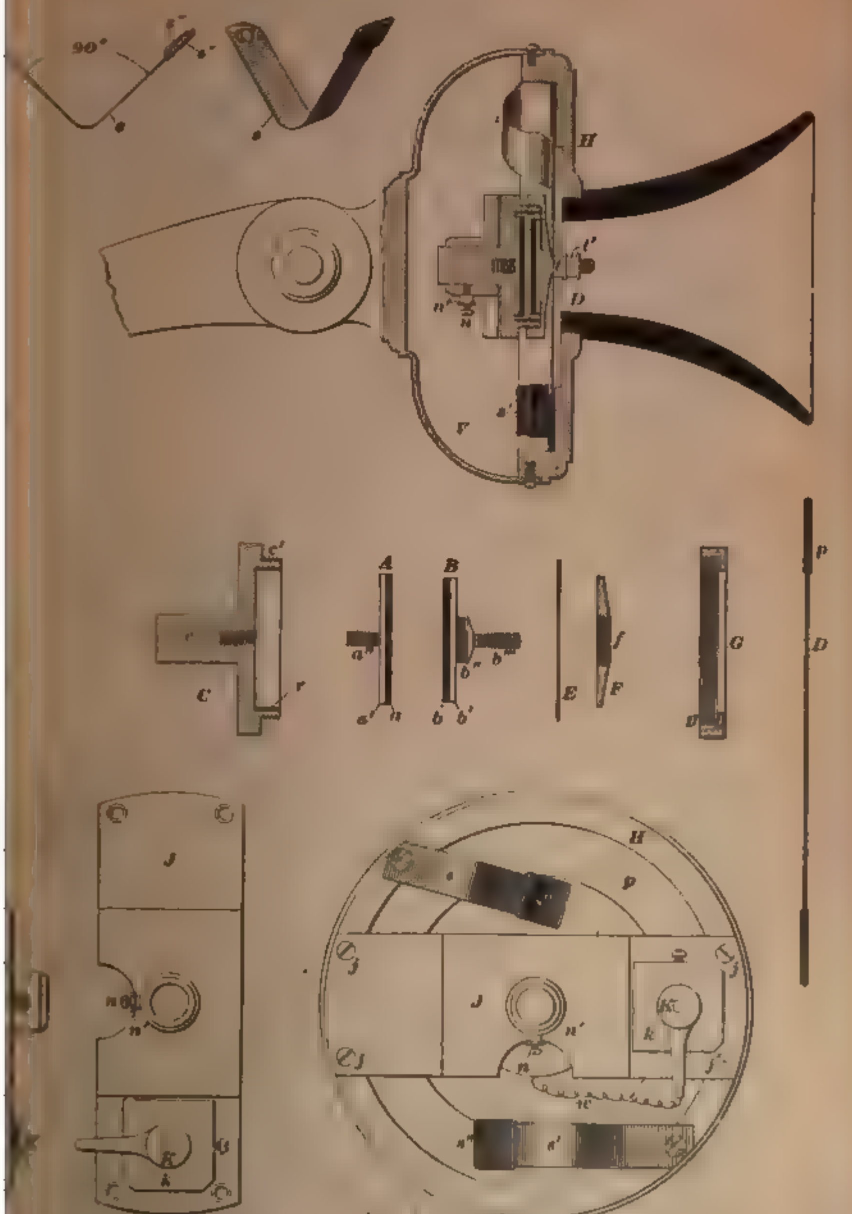


FIG. 1

between its edge and center. The spring *s'* bears against the rubber ring *p*. The damping springs *s*, *s'* are of spring steel $\frac{1}{100}$ inch thick and $1\frac{7}{16}$ inches long bent normally at right angles at their center points, as is shown in detail in the upper left-hand portion of Fig. 6.

14. The parts of the instrument forming the variable resistance devices are separately shown, considerably enlarged, in the central portions of Fig. 6. When assembled, these parts form what is termed the variable resistance button of the instrument, which is complete in itself, so that it may be entirely removed and replaced by another, in case the transmitter needs repairs. The black electrode *A* is composed of a carbon disk *a* secured to a flat brass disk *a'* forming the head of a screw *a''*. This electrode is secured in position in a chambered block *C* of brass by means of the screw *a''*. The diameter of the electrode *A* is somewhat smaller than the internal diameter of the chamber in the block *C*, so that a space is left entirely surrounding the electrode. The inner wall of the chamber is lined with a paper strip *r*, as shown in the detail figure of the block *C*. The front electrode *B* consists of a carbon block *b* mounted in a similar manner on a disk *b'* forming the head of the shouldered screw-threaded shaft having screw threads *b''*, *b'''*, as shown. *E* is a mica washer adapted to fit over the shoulder *b''* on the electrode *B*, and of sufficient external diameter to close the opening in the chamber in the block *C*. This washer is held in its position against the electrode *B* by a nut *F* having an internal screw thread *f* adapted to engage the thread on the shoulder *b''*. In assembling the button, the electrode *A* is secured in place in the block *C*, and the chamber is nearly filled with fine granular carbon. The electrode *B*, with its washer *E* secured in place, is then laid over the opening and clamped in position by the internally threaded collar *G*, the screw thread *g* on which engages the external screw thread *c'* on the block *C*.

The button, as a whole, is secured in place in the transmitter by means of the rearwardly projecting lug *c* on the

block C, which fits in a collar in a bracket J secured by screws j to the casting H. The button may be clamped in any desired position by means of the screw n and its lock-nut n', which passes through one side of the collar J. The forwardly projecting screw b''' of the electrode B passes through a central hole in the diaphragm and is secured in position by two small nuts t and t'.

The back electrode A, being firmly mounted on the frame of the transmitter, is held stationary, while the front electrode, being rigidly secured to the diaphragm D, is forced to partake of all of its vibrations to and fro. This vibration of the front electrode is rendered possible by the flexibility of the mica washer E. The vibrations of the diaphragm, therefore, produce corresponding variations in pressure between the two electrodes and the granular carbon between them, thus bringing about the microphonic action in a very perfect manner. The damping springs prevent an undue vibration of the diaphragm, corresponding to some particular rate at which it might be specially adapted to vibrate.

15. The entire transmitter is supported by a metallic shell V, from which it is readily removed when desired. This shell forms one terminal of the transmitter, as it is in metallic connection through the frame of the instrument with the back electrode A. The other terminal of the instrument is a brass clip K mounted on a fiber block k secured to the bracket J. This terminal K is electrically connected with the front electrode by means of a fine coiled wire w. The faces of the carbon electrodes in this transmitter are highly polished and perfectly plane. The space within the chamber is entirely filled with a comparatively fine granular carbon, the granules being of a very uniform size (not more than .021 inch or less than .019 inch in diameter). The average resistance of the White transmitter used on common-battery systems is about 35 to 50 ohms; it varies in resistance from about 18 to 90 ohms. It is said to work well in local-battery instruments with .32 ampere and in common-battery instruments with .17 ampere.

16. The **Kellogg transmitter** is shown in Fig. 7. On the frame of the instrument is fastened a bridge piece *h* of rather heavy sheet brass, used to support the rear carbon electrode, which is cemented to a brass piece *n*. The center portion of a mica diaphragm *e* is tightly held between the

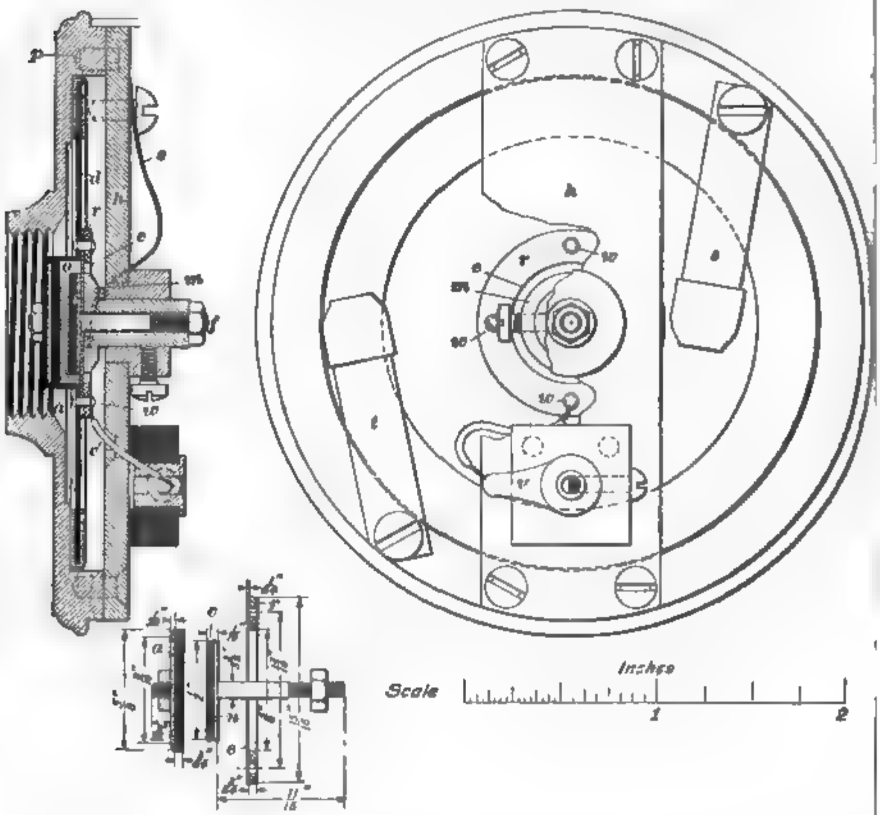


Fig. 7

two brass pieces *m*, *n* forming part of the rear electrode. The outer edge of this mica diaphragm is held between the hard-drawn aluminum diaphragm *d* and a small aluminum ring *r*, which are fastened together by rivets *w*. The diaphragm, which is about .025 inch in thickness, has a cylindrical recess formed at the center in which is placed the front

electrode. This consists of a carbon disk *a* cemented to a brass piece that is fastened tightly to the diaphragm by a nut on a projecting screw. The diaphragm has a rubber band around its edge and, including the front carbon electrode, is thus insulated from the frame of the instrument. The diaphragm is held in its seat solely by two damping springs *t*, *s* secured by screws to the frame. The end of each spring is covered with rubber, to the diaphragm side of which is glued a small felt cushion. The spring *s* bears directly against the diaphragm and the spring *t* against the rubber band around the edge of the diaphragm. The damping springs prevent an undue vibration of the diaphragm, corresponding to some particular rate at which it might be specially adapted to vibrate.

Both carbon electrodes are very highly polished, which is one of the most essential features of the instrument, and the rear one is somewhat smaller in diameter than the front one. The space *o* between the two electrodes is partly filled with a special grade of hard granular carbon, very uniform in size. The mica diaphragm insulates the front and rear electrodes from each other and the current must pass from the frame of the instrument through the rear electrode, the granulated carbon, the front electrode, diaphragm, and connecting wire v', to the insulated terminal v. The mica diaphragm serves not only to retain the carbon granules, but also as an auxiliary diaphragm, because as the front aluminum diaphragm vibrates the mica diaphragm must also vibrate to some extent since its edge is fastened to the front diaphragm and its center is held rigid by the back electrode. When the aluminum diaphragm vibrates, the pressure between the front and rear carbon electrodes on the granular carbon varies, and moreover the entire cell vibrates, which it is claimed tends to further shake up the granules. The construction of the carbon chamber prevents tampering with that part of the instrument and at the same time makes the chamber practically moisture-proof. The rear electrode may be clamped in any desired position by means of the screw *f*.

Two types of this transmitter are made, one for local-circuit systems, designated by the letter *L*, and one for

common-battery systems, designated by the letter *C*, these letters being placed after a serial number on the transmitter case. The two types differ only in the size of the parts contained in the carbon chamber.

17. The **Dean Electric Company's transmitter** has, for a front electrode, a light cup-shaped receptacle without a carbon or brass button. This receptacle is pressed by the two damping springs used against the edge of a circular opening in the diaphragm, of which it forms the center portion. In other respects, including the rear electrode and mica diaphragm, the Dean and Kellogg transmitters are similar.

The Century Telephone Construction Company makes a solid-back transmitter in which the active surfaces of the electrodes are platinum. Platinum surfaces with good granular carbon between them should give excellent articulation. Good mechanical construction, long life, and small current consumption are also claimed for this transmitter by the makers.

18. **Corn-plaster transmitters** are solid-back instruments having the rear electrode, which is usually carbon, rigidly mounted on a bridge piece. The front electrode may be carbon or metal secured to the diaphragm, or the diaphragm itself. An annular ring or washer of soft felt, flannel, or cotton, glued to the front or rear electrode, serves to confine the granular carbon in the space between the electrodes thus formed, and also to dampen the vibration of the front electrode. On account of the resemblance of the cotton ring to a corn plaster, transmitters of this type are sometimes called **corn-plaster transmitters.**

The Stromberg-Carlson and Williams transmitters are corn-plaster transmitters. Some makers do not use the carbon electrodes but use a gold-plated metal. Where the metal electrode is used, it should be of some material that will not corrode. For this reason gold- or platinum-plated brass is generally used.

19. The **Williams Electric Telephone Company's transmitter** is of the solid-back corn-plaster type; it has a

gold-plated rear electrode and the carbon granules are confined between the rear electrode and a carbon diaphragm by a ring of soft felt. The rear electrode is partly held in position by a German-silver spring, the end of which is gold plated (to insure a non-oxidizing contact) and tends to pull the electrode backwards at the center. This spring is said to assist in damping the vibrations. A comparatively thick carbon diaphragm, with a coating of shellac on the outside to keep out moisture, forms the front electrode. What carbon manufacturers term No. 26 granular carbon is used. It is thoroughly sifted, so as to get all the same size, and baked before assembling, so as to be absolutely dry.

The carbon diaphragms used in this and similar instruments are prepared from a very fine grade of ground carbon, mixed with a suitable binder, and molded under enormous hydraulic pressure to the required form; they are then placed on edge in an iron box filled with sand, and subjected to a suitable baking at a very high temperature. Several carbon manufacturers are now able to produce these diaphragms of a uniform thickness of not over $\frac{1}{100}$ inch. It has been found, however, that diaphragms slightly thicker than these give the best results, the usual thickness being from $\frac{1}{64}$ to $\frac{1}{50}$ inch. Much depends on the grade of carbon and on the method of baking these parts, as the elasticity and conductive properties of the carbon are greatly affected thereby.

All carbon-diaphragm instruments should be provided with some means of protecting the diaphragm against breakage caused by persons tapping against it with the finger or with a lead pencil. The most common protection is in the use of wire gauze or a mouthpiece with small holes through it, instead of one large hole, opposite the diaphragm.

20. The Stromberg-Carlson Telephone Manufacturing Company's transmitter has a rather heavy metallic diaphragm, the outside being covered with a rubber cloth that makes it moisture-proof. Both the front and back electrodes are flat circular pieces of gold-plated gauze, the front

electrode being riveted to the diaphragm and the back electrode to the inside or bottom of a metal shell or cup, the inside wall of which is lined by a felt ring which contains hard granular carbon. The metal cup is supported in the rear by a rigidly fastened bridge piece and may be readily adjusted at any desired distance from the front electrode, the play in the felt being sufficient to keep the carbon chamber closed. The makers claim that it can thus be adjusted so that one may talk at quite a distance from the mouthpiece, or, for noisy places, where it is necessary to talk very close to the mouthpiece. The diaphragm is held in position by two springs, as in the White and Kellogg solid-back transmitters.

OTHER FORMS OF TRANSMITTERS

21. The Colvin Transmitter.—In order to avoid the claims of the Berliner patent, covering all forms of transmitters depending for their action on the variation in resistance between two or more electrodes in constant contact, many attempts have been made to produce a transmitter in which the variations in resistance were brought about by some other means than variations in pressure between the electrodes. The problem has been attacked from nearly all conceivable standpoints. A transmitter, resulting apparently from one of these attempts, was produced some years ago by Mr. F. R. Colvin.

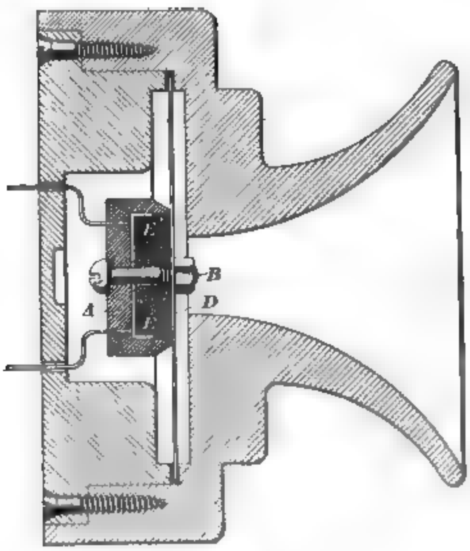


FIG. 8

It is shown in Fig. 8, in which D is a diaphragm of aluminum, mounted loosely in the enclosing case. A is a cup of insulating material, in which are mounted two metallic electrodes E and E'; these are permanently held at a considerable distance apart, and never come in contact with each other. The two wires forming the terminals of the transmitter connect respectively with these electrodes, the circuit between them being completed by the granular carbon placed within the cell. The cell A is rigidly fastened to the center of the diaphragm by the bolt B, as shown, the joint between the diaphragm and the edge of the cup being hermetically sealed by the introduction of some plastic material, in order to prevent the entrance of moisture. In this, the diaphragm and cell vibrate as one unit, there being no flexible connection whatever between them, the variations in resistance being caused by the variable contacts between the granules in the path of the current from one electrode to the other. This transmitter was capable of fairly good transmission, but the results were not good enough to warrant its adoption in practice.

22. Double-diaphragm transmitters usually consist of two parallel diaphragms to each of which is fastened one round electrode, the small space between the two electrodes being closed by a ring of soft, flexible, insulating material and partly filled with granular carbon. The two diaphragms generally occupy a position at right angles to the diaphragm of an ordinary transmitter and the sound-receiving cavities are intended to be so shaped that the sound waves will be reflected so as to strike at right angles on one surface only of each diaphragm.

The Fahnestock Transmitter Company makes a successful double-diaphragm transmitter. In the center of the chamber containing the transmitter parts is a fixed metallic block. In the center, on each side of this block, is a circular recess in which is held, by an insulating ring, a disk of mica to which is fastened a gold-plated electrode. A similar electrode is fastened to the center of each dish-shaped aluminum

diaphragm. The edge of the diaphragm is a trifle smaller than another recess in the fixed block, and when assembled this small space is filled and sealed with a thick solution of rubber, which prevents the sound waves from acting on the inner surfaces of the diaphragms. By means of insulating rings, the space between each pair of electrodes and in which the granular carbon is placed, is made practically air-tight. The only support of the diaphragms are the electrodes, to which each is fastened at the center, and the thick rubber solution, which is very flexible, around its edge. The two transmitter cells thus formed may be connected in series or parallel. The sound waves are reflected against the outside surfaces of both diaphragms.

23. It is possible to improve long-distance transmission in three ways, according to G. W. Wilder in "Sound Waves." The transmitters may be made more powerful, the receivers more sensitive, or the line able to carry the voice currents with less loss. By means of expensive copper lines, in which the conductors are of large diameter, well transposed and the capacity properly neutralized by inductance, as in the Pupin loaded-coil method, the transmitting circuit is made as good as is possible, at present. Furthermore, most receivers are already very sensitive, and, as a result, they pick up everything, including good and bad, that becomes troublesome on long lines, where ground currents and induction disturbances often render the voice currents indistinct. Hence, there is little to be gained by making the receiver more sensitive. There still seems to be room, however, for an improvement in transmitters, whereby they may be made to consume several times the amount of energy now used.

24. Adams-Randall Transmitter.—Mr. C. Adams-Randall conceived the idea that a transmitter might be built that would represent the simultaneous use of several independent transmitters. His idea involves the principles of a multiple-electrode transmitter, in which each electrode forms a separate and complete instrument by itself. Instead of using large carbon rods or balls, as in multiple-electrode

transmitters, a combination of the solid back with the multiple-electrode idea was employed. Granular carbon is placed between one diaphragm and several electrodes, which are insulated from each other; each transmitter cell so formed is supplied with current from a separate battery. Each battery is connected to an electrode, and thence the current passes through the carbon to the diaphragm that is common to all, and from this back to the various batteries through a common return circuit.

In Fig 9 is shown a cross-section and plan of this transmitter containing eight electrodes. Two pieces of hard rubber *a*, *b* form the front and back of the instrument, and between them is placed the diaphragm *d* that rests on a felt ring *e*. Four springs hold the diaphragm in place, one of them *r* being used as the terminal for a common return circuit. On the diaphragm is placed an octagonal piece of felt *k*, which contains eight holes that are partly filled with carbon granules, over which are placed the back electrodes. The electrodes are heavy cylinders of metal supported by strips of copper *n*, *m*, *o*. The strips bearing the electrodes are fastened to the hard-rubber frame of the instrument by screws *c*, the screws *p* being used to adjust the pressure of the electrodes on the carbon granules. When setting up this transmitter, each electrode is adjusted while being used alone in the circuit. Since inequalities in the resistance of the

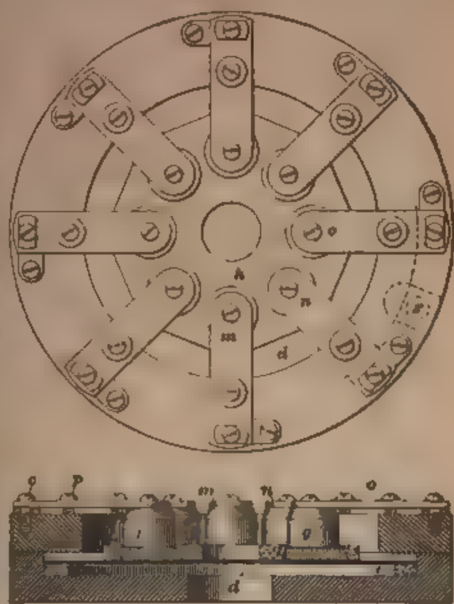


FIG. 9

various transmitter sections or cups would make the current through the various transmitter sections from a common source differ considerably in strength, it is advisable to use a separate battery for each transmitter section, or at least one battery for each two sections in multiple. The circuit from each section passes through the primary winding of an induction coil, a separate coil or at least a separate winding being provided for each section of the transmitter. Each battery may consist of six dry cells; although, in actual practice, the number would be varied to give the best results under the existing conditions. The quantity and quality of the granular carbon used in each section usually determines the battery power required for successful operation. The secondaries of the various induction coils are connected in parallel. It has been found better to use a separate coil for each battery circuit than one coil common for all. When a separate coil is used, the peculiarities occurring in the fluctuations of the primary current are faithfully reproduced in the line circuit. If a common coil is used, many of the fluctuations occurring in the various transmitter cells become more or less neutralized in the one primary coil, and hence do not reappear in the secondary. With one coil common to all the primary circuits, the intensity of the sound is considerably weakened.

It is said that both intensity and good quality are obtained and that this transmitter has given satisfactory results over lines of the Illinois Central Railroad from Chicago to New Orleans, a distance of 933 miles, consisting of a complete metallic circuit of copper wire weighing about 173 pounds per mile. According to reports made in September, 1905, the transmitters may have four, eight, or sixteen sections on one iron diaphragm, which is supported freely around the edge and not clamped to its support. For a four-section transmitter, the diaphragm is 4 inches in diameter and $\frac{3}{64}$ inch thick. The diaphragm of a twelve-section transmitter is $5\frac{1}{2}$ inches in diameter and $\frac{3}{64}$ inch thick. Carbon is used as a variable resistance, but it is confined in a fabric cup and under pressure, instead of the loose gravity contact of the ordinary transmitter. Any one section is said to be equal to one

ordinary transmitter, four sections of the later type proving as good as sixteen of the original form of this transmitter. The tests made are said to have been very successful, the transmission being sufficiently powerful for 1,000 miles and so powerful on shorter circuits (143 miles) that a receiver shunted and with its diaphragm $\frac{1}{4}$ inch from its pole pieces reproduced the speech plainly, while the induction from 50 neighboring telegraph wires in operation prevented the use of an ordinary telephone transmitter and receiver. About sixteen dry cells in series-parallel were used for each transmitter.

25. Breast-Plate Transmitters.—A transmitter secured to a plate that can be strapped to the operator's chest, so as to keep the transmitter before her mouth as she attends to her work, is called a **breast-plate transmitter.** It has long been used in Europe and is now being considerably used in the United States. It is more convenient than a transmitter hung by cords from the top of a switchboard, and moreover it enables each operator to have her own transmitter, which she can put away in her locker along with her receiver when she leaves for the day. The insertion of one plug in a spring jack connects both her transmitter and receiver to her position at the switchboard. The removal of the plug also acts as a switch to open the circuit between the transmitter and battery. The Ericsson breast-plate transmitter and head receiver, as used by a switchboard operator, is shown in Fig. 10.

FIG. 10

26. Transmitters for Common-Battery and Local-Battery Instruments.—The essential difference between

transmitters used in common-battery and local-battery telephone systems is in their resistance. In local-battery instruments the normal resistance may be about 15 ohms, while in common-battery instruments it is much higher. With the advent of central-energy systems, telephone designers apparently returned to primitive methods because in the first central-energy systems they connected the transmitter and receiver in series in the line circuit. However, they knew more about telephone apparatus, and so designed the transmitter and receivers to suit the new conditions. They used complete metallic circuits of copper wire, low-wound receivers (from 4 to 20 ohms in resistance), and high-resistance transmitters, from about 20 to 50 ohms. Thus, the variable transmitter resistance was quite an appreciable part of the total resistance of the line circuit. The higher the resistance of the line circuit and the higher the electromotive force of the central battery, the higher should be the variable resistance of the transmitter. Ordinarily, solid-back transmitters have an average resistance of from 35 to 90 ohms for 24-volt central-energy systems. However, the Kellogg transmitters now used in Buffalo on a 24-volt system, but with lines averaging rather longer than usual, are said to have a resistance of about 200 to 300 ohms. The transmitter made by the Eureka Electric Company for use on common-battery systems is said to have an average resistance of 80 ohms.

27. Transmitters may be designed to have most any resistance and current-carrying capacity by suitably varying the cross-section of the carbon electrodes, the distance between the electrodes, and the amount and resistivity of the carbon granules between the two electrodes.

The variation in resistance, which depends on the pitch and loudness, of local-battery transmitters is from about 5 to 30 ohms, while common-battery instruments may vary from 40 to 300 or more ohms.

Local-battery transmitters require about 3 volts and the current varies from about .33 to .1, or a change of .23 ampere.

The resistance of a common-battery transmitter must be large and its change in resistance must also be great, on account of the large resistance of the line circuit in which it may be connected. If a transmitter in a line circuit whose total resistance is 150 ohms, varies from 40 to 300 ohms, the resistance of the circuit varies from (150 + 40 =) 190 to (150 + 300 =) 450 ohms; and with an electromotive force of 30 volts, the current varies from .158 to .067 ampere, or a change of .091 ampere. This is a much greater change than will be obtained by connecting an ordinary local-battery transmitter in the same line circuit. It is the difference between the maximum and minimum values of the current that determines the loudness of sound produced at the receiver. Where induction coils are used, it is the difference between the maximum and minimum ampere-turns that determines the loudness of transmission. Local-battery transmitters can usually be refilled with the proper size of granulated carbon so as to work on common-battery lines, provided that the electrodes are of the proper size and distance apart; in any case, the filling must be determined experimentally.

Sufficiently satisfactory results could undoubtedly be obtained with the transmitter and receiver in series, if both were suitably designed, but the use of induction and impedance coils and condensers in connection with the subscriber's telephone instruments seems to give even better results and is replacing the more simple arrangement. However, the simple arrangement, consisting of a good transmitter and a 60- to an 80-ohm receiver in series across a metallic-copper-line circuit, has given almost perfect satisfaction for local-exchange work in a number of systems, including at least one of about 3,000 subscribers that was in operation in 1905.

PACKING OF GRANULAR TRANSMITTERS

28. One of the chief difficulties encountered in the operation of granular-carbon transmitters is that known as **packing**. This trouble may be attributed to several causes, and

in each case consists in the granules settling into a compact mass, so as not to be sensitive to changes in resistance. Probably the most common cause of packing is the using of carbon granules of different sizes, so that they gradually settle into a compact mass, the large ones rising to the top and the small ones settling to the bottom and filling in all the interstices between the large ones. In other cases, packing is caused by moisture entering the carbon chamber, either from the breath or from dampness in the atmosphere. Still another cause is the wedging of several granules between the electrodes in such a manner as to hold them farther apart than when in their normal position and prevent all vibrations of the diaphragm. In most cases, a thorough agitation of the granules will remove the defect, temporarily at least. If, however, it is due to moisture, the transmitter should be refilled and, if possible, means provided for preventing the entrance of moisture again.

In the best makes of transmitters, particular attention is paid to obtaining granules of uniform size; this is usually accomplished by sifting them through screens having a certain number of meshes to the inch. Thus, in the solid-back transmitter, only those granules are used which will pass through a screen having fifty meshes to the inch, but will be retained by a screen having fifty-five meshes to the inch.

As an illustration of how packing may be caused by the wedging action of the granules between the electrodes, almost any granular-carbon transmitter may be packed by placing the mouth firmly against the mouthpiece and sucking in the breath. This draws the electrodes apart and allows the granules to settle lower in the chamber. When the pressure is removed, the electrodes tend to assume their normal position, but cannot do so on account of being held apart by the granules. As a result, a considerable pressure is exerted on them and the conditions of loose contact destroyed. After such treatment, a transmitter will usually be found to be perfectly "dead," and its efficiency can only be restored by reagitating the granules.

29. Prevention of Packing.—When granular-carbon transmitters were first introduced, the trouble due to packing was so serious as to call forth much attention on the part of inventors to produce means for its prevention. Most of these consisted in some means of mechanically agitating the granules at frequent intervals. In some, a spring was arranged within the carbon chamber of the transmitter with a trigger projecting outside of the casing, by means of which the spring might be made to vibrate among the granules, thus effectually stirring them up.

A later device that was used to a limited extent consisted in so mounting the transmitter that the mouthpiece could be used as a handle to rotate the case containing all the working parts of the transmitter. Contact springs were arranged to preserve contact between the wires leading to the transmitter and the two electrodes in the transmitter cell. An occasional turn on the mouthpiece would bring about an entire rearrangement of all the granules within the chamber, thus effectively relieving any packing. This arrangement, while answering the purpose for which it was designed, introduced two sliding contacts in the primary circuit of the transmitter—a very objectionable feature, because the corrosion of the metal surfaces between which the contact takes place, or the collection of dust between the contacts, will often cause a break in the circuit or a point of high resistance, thus rendering the transmitter practically inoperative.

This idea of rotating the transmitter was further developed by a number of inventors, who arranged mechanism for accomplishing the rotation automatically, the usual plan being to use a pawl, carried on the lever of the switch hook, which, in its operation up and down, would engage the teeth of a ratchet wheel carried on the transmitter itself. Every time the telephone was used, the hanging up of the receiver would cause a partial rotation of the transmitter, thus always maintaining the granules in state of loose contact. These devices, however, have gradually dropped out of use, as the later and best forms of transmitters are comparatively free from the trouble of packing. The benefits to be derived

from such mechanisms are not, therefore, sufficient to offset the undesirable complexity and the disadvantages of having one or more movable contacts introduced into the circuit.

The use of carbon granules of uniform size has probably been the greatest factor in improvement in the operation of transmitters, with regard to a reduction of the packing. Apparently, the form of a carbon chamber also has considerable effect on the liability of the instrument to pack. In the White transmitter, the space around the periphery of the two electrodes was left for the purpose of allowing room for expansion of the particles between the electrodes, which are directly in the path of the current, and therefore subject to a greater amount of heating than those around the periphery.

TRANSMITTER TROUBLES AND THEIR REMEDIES

30. There is probably no granular-carbon transmitter that will not pack under certain conditions; but this packing can usually be remedied by giving the instrument a sharp blow from beneath with the soft portion of the hand in such a manner as to disengage any particles which have become wedged. It can also be remedied by turning the instrument upside down. If packing occurs frequently, the granular carbon should be changed; and if this does not remedy the trouble, return the transmitter to the maker as defective. Subscribers should never be encouraged to tap a transmitter, as is frequently done by operators and inspectors, for this practice is very likely to soon spoil the adjustment. A frequent trouble with transmitters is a frying noise, which is usually caused by too strong a current or by loose connection.

Other faults are loose contacts, bad joints, and damaged diaphragms. Loose contacts and bad joints have to be cleaned and tightened, or soldered, as the case may be. Damaged diaphragms must always be replaced by good ones.

An inexperienced person should not attempt to readjust a solid-back transmitter, nor is it best to take it to pieces unless thoroughly acquainted with its construction, to know which, it is well to practice on a defective instrument. Defective

transmitters should generally be returned to the workshop or maker.

With solid-back transmitters, the best results are usually obtained by talking directly into the mouthpiece, with the lips quite near but never touching it.

DESIGN OF MICROPHONE TRANSMITTERS

DIAPHRAGM

31. The design of transmitters has been very well treated by W. A. Taylor in the Electrical Review, from which the following is abstracted: The space between the diaphragm and the front case of a transmitter need not exceed $\frac{3}{32}$ inch; if too large it is apt to cause disagreeable echoes. Too large a mouthpiece will also tend to cause disagreeable echoes. A perforated guard, while perhaps not very good from the standpoint of efficiency, is nevertheless almost a necessity to protect the diaphragm.

32. Material for Diaphragms.—The diaphragm should be very resilient and should give continuous service under all conditions with no appreciable deterioration. It should be made of such dimensions that it can vibrate very rapidly and yet be properly damped so that it will stop almost instantly when impulses cease, otherwise it will not articulate plainly, but will have a muffled sound. Nothing is gained by having too large an amplitude of vibration and there is no decrease in loudness when the diaphragm is very heavily damped, provided that the amplitude is not less than required. The material for the diaphragm should be springy and also light, to give the best results, and it should not be loaded with the heavy parts of the transmitter, for the inertia tends to make it sluggish. Carbon diaphragms have given good results, but they have the disadvantage of being broken easily and of absorbing moisture. Wood has also been used, but it is almost impossible to get two such diaphragms exactly alike. Iron, steel, and brass have been used very extensively and successfully, but the ideal substance

now seems to be hard-rolled aluminum. This is an extremely light metal and has, therefore, little inertia.

33. Size of Diaphragms.—The thickness and diameter of the diaphragm are determined entirely by experiment. Generally, one can say it should be as thick and as small in diameter as is consistent with sufficient vibration. There is no hard and fast rule to apply, as it will vary with any change in the other details of the instrument. With a decrease in diameter, it must of course be made thinner. If it is made too thin, it can easily be bent out of shape. If it has too great a diameter, it may cause the current to break entirely, which would cause it to cease and make the voice sound hollow. If Bell practice is to be followed, the diaphragm should be made of hard-rolled aluminum $2\frac{1}{4}$ inches in diameter and No. 24 B. & S. gauge. This size, or close to it, has been adopted by most of the leading telephone manufacturers of this country.

34. Damping springs not only limit the amplitude of vibration, but also eliminate, to a considerable extent, the side tones due to noises in the room; they also prevent the diaphragm from breaking into subdivisions that produce even tones and tend to spoil the quality of transmission. They also prevent, or at least reduce, packing. Rubber around the edge acts not only as an insulator but also as a damper, and gives a continuous bearing around the edge. It is of importance that the very best grade of rubber be used for this purpose, because if the rubber gets hard the good effect is immediately lost.

35. Current Required.—The resistance of a transmitter in a local-battery instrument should be made high because just as small a current as possible should be used, in order that the battery may last a long time. A battery giving $\frac{1}{6}$ ampere to the transmitter will last three times as long as one that furnishes $\frac{3}{6}$ ampere. Besides the cost of the battery, there is the expense of two extra inspections where the larger current is used. In an exchange of 200 or more subscribers, this item would mean a great deal. A transmitter

that will do first-class service on local-exchange work should not take more than .2 ampere, and for long-distance work it will do the best service with a consumption of from .30 to .35 ampere. These figures are only for local-battery instruments. Such a transmitter need not have the electrodes larger in diameter than $\frac{5}{8}$ inch, with a separation of $\frac{1}{16}$ inch, and granular carbon of the polished coal grain variety of a size to pass through a screen 30 meshes per inch and too large to pass a 35-mesh screen.

ELECTRODES

36. It is generally conceded that the greater variation in resistance takes place between the granular carbon and the vibrating electrode, and the contact between the granules themselves does not vary so greatly except in the near proximity of the vibrating electrode. For this reason, the two electrodes are placed as close together as possible, without danger of packing or wedging of the particles between them. The space between the electrodes in most forms of transmitters varies from $\frac{1}{16}$ to $\frac{3}{16}$ inch.

The diameter of the electrode varies in different makes from nearly the full size of the diaphragm, when the diaphragm is carbon, down to $\frac{5}{16}$ inch.

It is not, at present, considered good practice to have very large electrodes as the resistance of the transmitter becomes too low, making it consume too much current, and also presenting difficulties due to the packing of the great quantity of granular carbon required. It is not to be understood that such a transmitter will not talk loudly and as well as the best, but it is a matter of extravagance to use $\frac{3}{4}$ ampere when a transmitter that can talk just as well may be made, consuming not more than $\frac{1}{5}$ ampere.

When the electrode is made of carbon, it should be plain, very highly polished, homogeneous, hard, and of good conductivity. When they are of the softer grade, there is a greater danger of burning from the current. This burning manifests itself by a sizzling sound, which is very disagreeable and interferes with the action of the instrument. When

the carbon is hard, it resists the burning effect and especially so when the surface is polished. Polishing is very important, as it improves the articulation and increases the current-carrying capacity, allowing it to carry from two to three times the normal current without the disagreeable frying and sizzling noise so often noticed with excessive voltage. This frying noise seems to be the result of arcs created either between the particles of the granular carbon or between the electrodes and the granular carbon.

37. Polishing Carbon Electrodes.—The carbon electrodes may be given a very high polish in the following manner: The first requisite is to have the carbon perfectly clean, both internally and externally. If it has been plated on the back and soldered to a support, it should be cleaned so as to remove all the chemical from the plating bath and the acid used in soldering. This may be done by boiling thoroughly in water for several hours. If the carbon has been soldered with paste or handled by the fingers, it should be soaked for 12 hours in gasoline or benzine to dissolve out all the grease, and after coming out of this bath it should be thoroughly dried. After this cleaning, the carbon should not be touched on the face by the fingers or anything else that is apt to leave a film of grease on it.

The carbon disk should be accurately scraped off so that there will be no scratches on it whatever. If there is the slightest scratch or inequality, it will show up immediately when it touches the polishing wheel. One way to face off the disk is by means of a diamond or sapphire tool after placing the carbon in the chuck of a small and very accurate lathe. Constant care must be taken to keep the tools in good repair, as they soon get dull. The hardest tool steel ever made will not last long enough to face one electrode, as the edge is ground off immediately. On account of the difficulty of keeping the tools in repair, the following method will prove cheaper and works very well: Mount a piece of slate slab on a face plate and face off the electrode on this wheel. A constant flow of water must be supplied or the

face of the wheel will soon fill up and glaze. The electrode should be kept moving around the wheel, working all over the surface from the center out and then back again, moving the carbon in circles in order to wear all parts of the surface of the slate equally and so that the carbon does not become streaked. The slate sooner or later will become worn in grooves, and also get too smooth, so that every hour or so it should be dressed by applying another flat slate against its face and grinding it down. After having faced off the carbon, it is thoroughly dried and then applied to the polishing wheel.

The polishing is done by holding the electrode flat against a revolving carbon plate, and in a few seconds, if the electrode has been properly faced, it will show a polish equal to glass. The electrode should be kept moving in polishing in the same manner as when facing off. Care must be taken in both cases to hold it properly flat all the time. It is always better to trim the edges smooth and square before polishing the face, as it makes a much better mechanical finish. The electrode is placed in the chuck of a lathe and trimmed off with a diamond or sapphire tool, or a piece of fine emery cloth fastened to a stick will do, but not so well, as any solder is apt to fill up the cloth so that it will not take hold. There is also danger of chipping the edges with the cloth.

38. Size and Distance Between Electrodes.—Separating the electrodes will give an increased resistance to the transmitter, but that is not advisable after an efficient separation is decided on, as the variation of resistance is reduced, because the particles of carbon midway between the electrodes would be very little affected by the vibration of the diaphragm. Generally speaking, it is well to have the electrodes as close together as possible without causing the granular carbon to wedge between them. The distance apart should be sufficient, so that three granules in series will just reach from one electrode to the other. This will not permit the granules to wedge. The effect of wedging of the granules is

similar to that of packing, but worse, as the transmitter is completely short-circuited. Sometimes, a transmitter acting this way will have to be taken apart completely and the offending granules removed. It is usually caused by an extra large piece, which is long but narrow enough to pass the screen. As long as this piece does not extend its length, from one electrode to the other, there is no trouble.

By reducing the size of the electrodes, the resistance may be increased also, and this method, together with the reduction of the size of the granules, is the proper way of making any necessary increase in the resistance. In decreasing the size of the electrodes, care must be taken not to make them so small that they will not have sufficient capacity to carry the necessary current for efficiently operating the transmitter. In such a case, there would be trouble due to frying. Probably the smallest size for this purpose, which has proved satisfactory, is about $\frac{7}{16}$ inch.

GRANULAR CARBON

39. The size of the granular carbon used depends largely on the design of the transmitter. If the carbon electrodes are large or close together, the granular carbon may be larger than when the electrodes are small and far apart. Where the transmitter is to be used for central-energy systems, its resistance must be greater and therefore the granular carbon must be graded accordingly. With a given grade of granular carbon and with a given size of the transmitter parts, the finer the granular carbon the higher will be the resistance. A transmitter having No. 30 carbon (thirty meshes to 1 inch) and normally a resistance of 20 ohms, will have a normal resistance of about from 60 to 70 ohms when a carbon between 50 and 60 gauge is used. It is not exactly proportionate, probably because the lighter weight of the smaller particles will not cause so great a pressure at the points of contact.

The quantity of granular carbon that should be placed in the transmitter depends of course on the type of instrument.

Where the chamber for holding the carbon is very large, as in those with carbon diaphragms, where nearly the whole of the diaphragm acts as an electrode, the weight of carbon would be too great if filled anywhere near full and there would be great trouble from packing. The transmitter would then give very indifferent service. In this class of instrument, the granular carbon is filled up to a point about half covering the electrode, where it gives best satisfaction. In the small button transmitters, the usual custom is to fill from three-fourths to five-sixths full. A little space must always be left to insure absolute looseness of the particles.

40. Quality of Granular Carbon.—An important step in the design of a transmitter is to choose the granular carbon. Several kinds have been used with varying degrees of success. A number of European manufacturers have shown a preference to **globular carbon**, which is in the shape of small round balls. It is soft and disintegrates easily; it does not act efficiently, is apt to sizzle and fry with a very small current, and gives very poor results compared with any other kind. A better variety is made from granulated coke carefully screened to a uniform size. This variety gives good results, but is also soft and is apt to have the same faults as the globular carbon, only in a lesser degree. The action of the transmitter seems to powder a portion, and this powder gives rise to burning or frying.

The best grade is the bright, shiny, sharp-cornered granular carbon. The particles of this carbon are very hard and should have a deep, glossy, black hue. All particles should be uniform in size and of as low a resistance as possible. There is nothing to be gained in using carbon the material of which possesses a high resistance; the resistance should be in the points of contact, as that is the only resistance that is variable. To increase the resistance, an entirely different method should be used.

41. Manufacture of Granular Carbon.—The best grade of granular carbon is made from very hard and pure anthracite. Cross Creek Lehigh coal is eminently fitted for

this, as it is very hard and nearly pure carbon, having an extremely small percentage of ash and volatile matter in its composition. The coal should not be taken from the heap at random, but only the clean, shiny, crystalline pieces should be chosen, those showing no stratification or parts having the dull appearance of slate. The pieces containing dirt and other impurities should be rejected, as they will be soft after treatment. The good pieces should be broken up to about the size of a walnut and carefully inspected again for the presence of impure-looking particles.

After picking over, place into a graphite crucible and cement the cover on with fireclay. The crucible should then be placed in a furnace and heated to almost a white heat for 12 hours, and then should be allowed to cool before opening. During this process, all the volatile matter in the coal is driven off and all the other substances are thoroughly carbonized. The chief difficulty in the process is to know when the coal is sufficiently carbonized, for if the coal still contains uncarbonized matter, its electrical resistance will be abnormally high. Care must also be taken to guard against the admission of air while the coal is heated.

After the coal has been thoroughly carbonized, it is removed from the crucible, crushed and screened to the proper size. The screening process must be carefully done or the granules will not be of uniform size. A large amount of waste is always left, which is of no use. This waste includes all sizes that pass through a screen of sixty meshes per inch and consists mostly of dust. The granular carbon will have a dense, jetty black shade, the particles of which will be very brilliant in luster and intensely hard; in fact, hard enough to scratch glass. The electrical resistance will not be high, and, on account of its hardness and polished surface, will stand very heavy currents without burning. Such carbon will have a long life with very severe usage.

42. The **adjustment** of a transmitter is distinctly a mechanical feature, but of great importance in the working of the instrument, as it affects the uniformity of the action.

All the transmitters should be made so that in any number there will be no variation in the different dimensions. Especially is it necessary that the diaphragms shall be of uniform gauge and resilience. The damping springs should all be alike, pressing as nearly as possible with the same tension and in the same position in each case. Provision should be made to hold the electrodes a certain definite and known distance apart. Toward this end all parts should be made exactly alike and hence absolutely interchangeable. This, of course, means expensive tools made especially for this purpose, and while they cost considerable they will quickly pay for themselves on account of the economy in assembling. It never pays to skimp in the toolroom and turn out inaccurate tools, for many times their worth is lost in fitting at the assembling bench, both on account of the time required and because of the skilled help then necessary. With good tools, cheap help may be used in assembling. This truth applies to all parts of telephone apparatus.

TELEPHONE APPARATUS

THE INDUCTION COIL

1. The **induction coil** used in local-battery telephone instruments is, almost without exception, made by winding on a suitable spool a comparatively small number of turns of coarse copper wire, and on the outside of this a large number of turns of fine copper wire. Within the spool is placed a bundle of soft-iron wire, forming a core. The general appearance of the coil ordinarily used with the Blake transmitter is shown in Fig. 1, and its internal construction in Fig. 2. It consists of two square wooden heads H, H glued to a paper tube T, around which is wound a primary coil of 3 layers of No. 24 B. & S. single cotton-covered

FIG. 1

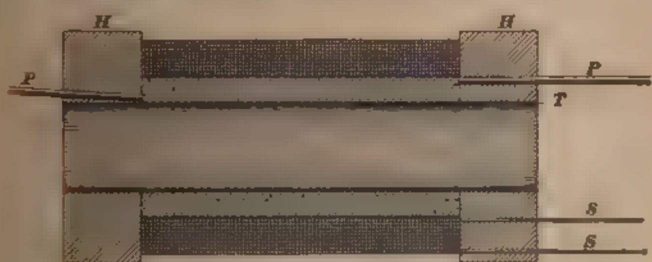


FIG. 2

wire. Over this are wound several layers of waxed paper and then a secondary coil of No. 36 B. & S. single cotton-covered wire, and finally a layer of bookbinder's cloth, to

hide defects in winding and to protect the wires. The core is $\frac{1}{4}$ inch in diameter and is composed of soft-iron wire. The resistance of the primary winding in this coil is usually slightly less than $\frac{1}{2}$ ohm, while the resistance of the secondary coil is about 250 ohms. This coil is, therefore, commonly spoken of as a 250-ohm coil.

DESIGN OF INDUCTION COILS

2. The induction coil best suited for one transmitter will not give the best results with another; it is therefore desirable to design a coil with reference to the particular make of transmitter with which it is to be used. Unfortunately, the complexities of the problem are such as to render its treatment from a mathematical standpoint, with the object of producing practical results, out of the question. The method usually employed, therefore, is one of comparison, a large number of coils of various proportions and resistances being tested with a view of finding out which will produce the best results. In choosing the proportions of the trial coils, the experience of others may be used as a guide within certain limits.

3. A convenient method, in case a somewhat extensive investigation is to be made, is to decide on a certain dimension and length of core, and then to wind perhaps ten of them with primary coils, using different sizes of wire and with varying numbers of turns. Ten secondary coils may then be wound on thin spools, each one adapted to fit snugly over any one of the trial primary coils. Suppose that each of the primary coils and also each of the secondary coils is numbered consecutively from 1 to 10, and that a certain primary, say No. 1, is chosen and tested with each of the ten secondaries in succession. The combination producing the best result is noted. Primary coil No. 2 is then tested, using each of the secondaries in succession, and the best combination again noted. Similarly, the best combination between the various secondaries and each of the primaries may be determined. It now remains to choose in the same manner

between the ten combinations of primary and secondary determined on. In this manner, by winding ten primaries and secondaries, a choice may be had from the equivalent of one hundred induction coils, thus making it possible to cover a wide range with a comparatively small outlay.

4. Some maintain, says W. A. Taylor, in the Electrical Review, that a very large ratio between the windings should be adopted, while others have gone to the other extreme. Of the two sides, the latter has the better of the argument. It has been shown by actual tests that the lower-wound secondary gives better results in voice transmission. There are, however, occasions when the higher-wound secondary is to be preferred, even if the transmission is to be sacrificed somewhat. Should a high-wound coil *A* be placed at one end of a line and a low-wound coil *B* at the other, the party at the instrument with the low-wound coil would hear better than the party at the other end; this would seem to show that the high-wound induction coil transmits better than the low-wound coil. This is not a fair test, however, because the current induced in the low-wound secondary of coil *B* has to meet the high impedance of the high-wound secondary of coil *A*, while the current induced in *A* meets a low impedance in *B*; it is therefore easily seen why there is a difference. It is best then to always test with coils alike on both ends, or the results will prove misleading. To get the best results in transmission, it is better not to have more than about 4,000 turns on the secondary and about 75 ohms. The primary winding will depend largely on the transmitter that is used. The larger the primary current, the smaller should be the number of turns in the primary; for if there are too many ampere-turns, the core of the coil will be magnetized above the saturation point and consequently a change in the current will produce too small a change in the magnetism. The density of magnetism should be at about the steepest part of the magnetic curve, so that a given change in the ampere-turns will produce the greatest effect on the core.

5. Iron for Cores.—The material of the core has a great deal to do with the efficiency of an induction coil. The core, to produce the best results, should be composed of small Norway iron wires, preferably not larger than No. 24 B. W. G., annealed after straightening and cutting. If the core were to be made of solid iron it would act sluggishly, because of the eddy currents that are induced in it. For this reason, the core is made up of a bunch of wires. It is better if the wires have a thin coating of iron oxide or varnish, as either substance acts as an insulator to the low-voltage eddy currents. The iron should be exceedingly soft, so that the permeability will be as great as possible. With hard iron, it is difficult to change the magnetism, and a great deal of the energy supplied by the current is lost. The soft iron produces a core that acts very quickly.

It has been found that the best results are obtained where the length of the winding on the spool is about three times its diameter. A long thin coil allows too many lines of force to escape between the turns of the winding instead of passing within all the turns. The primary should be wound next to the core, with the secondary directly above. The core should be insulated with at least $\frac{1}{64}$ inch of paper or fiber, and a like thickness should separate the primary from the secondary. All windings should be in uniform layers, as the insulation is then less apt to break down under a strain due to lightning or other high-voltage currents.

6. Durability.—Induction coils should be made durable. As one side is connected directly to the line, it is very susceptible to burn-outs from discharges of static electricity with which the line may be charged. Therefore, thoroughly insulate every part of the winding and use wire as large as is consistent. It is especially important to insulate the ends of the spool next to the core. Probably nine-tenths of the burning out of all kinds of coils used in telephone work comes from the poor insulating of the wire at the end of the spools next to the core. In fastening the paper used in insulating, a paste without acid should be used; the various

white pastes used by photographers for mounting prints are excellent for this purpose. In case of a break in the wire, the splice should be carefully soldered and a piece of paraffined paper should be folded over the joint; no acid or acid paste should be used for soldering. In local-battery induction coils, the primary should be wound in one piece, because, on account of the coarse wire used, a joint would make a large lump and be apt to cut into the insulation of the layer above or below it and cut out part of the coil.

7. Differences Between Good Coils.—To illustrate the difference in the induction coils that have been found to give the best results with different transmitters, the following table is given.

TABLE I

Transmitter	Primary Ohms	Secondary Ohms	Length Inches
Blake	.48	250	$2\frac{1}{2}$
Western	.38	70	4
Solid-back	.50	14	6

The resistance of the secondary used with the solid-back transmitter is surprisingly low, and demonstrates, perhaps, the extreme limit toward which the tendency in the construction of induction coils has been in recent years. It was commonly supposed, particularly among the independent companies, that the higher the resistance of the secondary of an induction coil, the better would be the result; and it was not uncommon to find 500-ohm and even 750-ohm coils. Such specifications, if adhered to, often proved decidedly detrimental to the service, for reasons that will be made more apparent later.

CONSTRUCTION OF INDUCTION COILS

8. A well-constructed coil suitable for use with solid-back transmitters is shown in perspective in Fig. 3. The spool is composed of two square fiber heads glued to the ends of a fiber tube. The primary winding consists of two layers of No. 20 B. & S. gauge single silk-covered copper wire. Over this is wrapped a layer of waxed paper, on which is wound the secondary winding, which consists of two No. 34 B. & S. gauge single silk-covered wires wound on at the

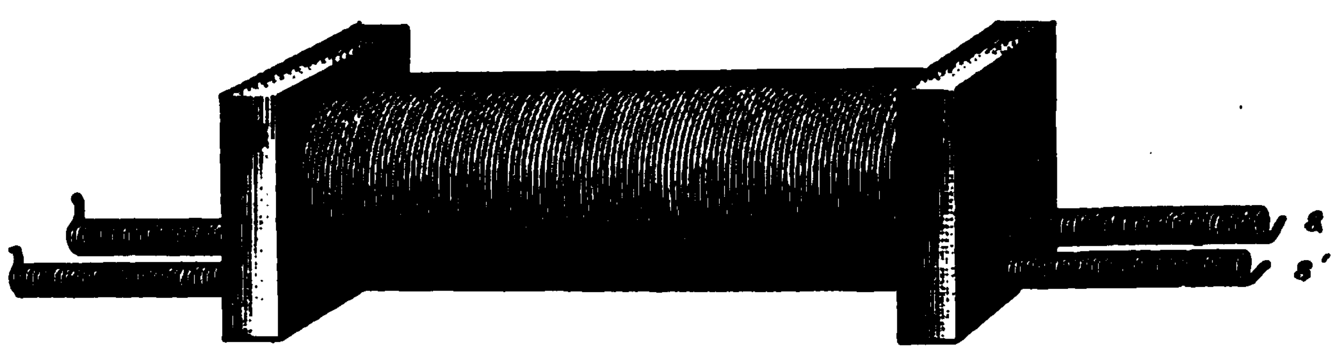


FIG. 3

same time, so as to be parallel throughout their entire lengths. The resistance of this secondary coil is 70 ohms. Heavy wires *s* and *s'* are connected to the fine-wire terminals of the secondary winding at points within the spool, and these are led through the heads of the spool in the ordinary manner. This is done as a precaution against breakage of the very fine wires in handling.

9. Varley Coils.—An innovation in the art o coil winding has been introduced by the Varley Duplex Magnet Company. Their method is, wherever possible, to wind with bare wire. In order to prevent the short-circuiting between the various convolutions, a silk thread is wound parallel with the bare wire throughout its length, so that the adjacent convolutions are always held a slight distance apart. Between the several layers of the winding are introduced thin layers of oiled paper. This winding is accomplished entirely by automatic machinery, and the coils produced are nearly perfect. The machines are run at a high speed, and at the proper intervals the layers of paper are introduced without stopping the machine or without the volition of the

operator. This method, while being cheaper than the ordinary method, in which insulated wire is used, has also the additional advantage of making possible a given number of turns of a certain size of wire in a smaller space than can be obtained by the old method. Again, the convolutions are arranged with practically perfect uniformity, in decidedly sharp contrast to the results produced by the usual method, in which the wire is fed to the machine by hand.

10. The following are the dimensions of an induction coil commonly used by the Bell companies with the solid-back transmitter in local-battery instruments: diameter of core is .25 inch; length of core, 3.75 inches; length of winding space, 3 inches; dimensions of head, 1 inch square, $\frac{3}{8}$ inch thick. The core is composed of 150 No. 28 B. W. G. Norway iron, annealed and surface oxidized after straightening and cutting. The thickness of core insulation is $\frac{1}{32}$ inch; the primary has four hundred turns of No. 26 S. S. C. copper wire, measuring 1.62 ohms, and the secondary, one thousand eight hundred turns of No. 28 single cotton-covered copper wire, 21.8 ohms. The terminals of the secondary are reenforced, being two strands of the No. 28 wire. This coil is used with a normal current of from .25 ampere to .45 ampere and gives very good service. This coil is somewhat different from the coil of the same type previously used, as the resistance of the secondary is higher. This is due to a change from silk-covered to cotton-covered wire. The cotton-covered wire occupies more space than silk-covered wire, and therefore the resistance is higher for the same number of turns.

11. Another first class coil is wound on an annealed iron wire core, $\frac{3}{8}$ inch in diameter, with a head $1\frac{1}{4}$ inches square. The primary has four hundred turns of No. 24 B. & S. single cotton-covered wire of 1.6 ohms resistance; the secondary, two thousand turns of No. 30 B. & S. single cotton-covered wire measuring 40 ohms. The length of winding is $3\frac{1}{2}$ inches.

12. For a very small coil, the following is a good design: diameter of annealed-iron wire core, $\frac{1}{4}$ inch; heads, $\frac{3}{4}$ inch

square; length of winding space, 2 inches; primary, three hundred and fifty turns of No. 24 single silk-covered wire, resistance .9 ohm; secondary, two thousand turns No. 33 single silk-covered wire, resistance 90 ohms. In this coil, the secondary is a little high in resistance. Should the primary be wound with No. 26 wire and the secondary with No. 32 a better proportion would be reached.

13. Williams Telephone and Supply Company's induction coil has a fiber tube $\frac{3}{8}$ inch inside diameter and 4 inches long, with square fiber heads $1\frac{1}{2}$ inches square, glued or shellaced on the ends of the tube. The tube is filled with iron wire before the wire is wound on, as this secures the heads tighter and gives more rigidity to the frame and also prevents trouble from the heads turning and core bulging, thus causing open circuits or short circuits. The primary consists of four layers of No. 24 B. & S. single cotton-covered wire, thus making both leads come out of the same head. The secondary consists of twelve layers of No. 34 B. & S. single silk-covered wire, and measures approximately 250 ohms, a variance of 10 ohms each way being permissible. Between each layer of the secondary is placed a layer of paper, to give a smooth winding surface and also to prevent a high voltage discharge jumping from one layer to the other. A layer of bookbinders' cloth or imitation leather is pasted over the coil to prevent injury to the wire. Small brass clips, or *terminals*, are secured into the heads on top of the coil to which the lead wires are soldered.

14. Induction Coils for Central-Energy Systems. When used in connection with central-energy systems, the induction coil assumes an entirely different design as to the primary winding; the number of turns becomes greater and the resistance higher. In this case, the current used is very much smaller, and consequently the turns are greater. The coil is usually placed in circuit in an entirely different manner than with the local-battery systems. Where induction coils are used, there is little or no gain in the loudness of the transmission, but the quality is considerably better than

where the transmitter and receiver are connected in the line circuit. Another duty that an induction coil is sometimes used to perform, is to enable the placing of the receiver in a local circuit, thus preventing a direct current from the central-office battery from passing through and demagnetizing the receiver magnet, as would be the tendency if the receiver was incorrectly connected in the line circuit. The use and connection of induction coils in central-energy telephones will be considered in connection with the various central-energy exchange systems.

TESTS OF INDUCTION COILS

15. A systematic set of experiments was carried out in the electrical engineering laboratories of the Iowa State College, in 1902, to determine whether any definite relation exists between the dimensions of the coil (that is, between the length of the core, diameter of core, and ratio of turns in primary and secondary windings) and the efficiency with which an induction coil transmits speech, considering both the intensity, or volume, and the clearness of the sound produced at the receiver, as compared with the same properties in the sounds spoken to the transmitter. According to the American Telephone Journal, in which the results were published, twenty-two pairs of coils, four pairs of which were made in prominent telephone factories, were tested; eighteen pairs were made expressly for the test, some being made according to data furnished by well-known telephone manufacturers. The spools for these coils were made by gluing together several layers of paper to which were glued heads made of walnut wood. The primary and secondary windings were separated by two thicknesses of rice paper, care being taken to make the coils first class in every particular. Two exactly similar coils were made of each design; the dimensions of the coils are given in Table II.

Two stations *A* and *B* were established in different rooms, each station being equipped with exactly the same apparatus; the connections at each station are shown in Fig. 4. Each

station had twenty-two induction coils, similarly arranged. One induction coil, No. *21*, was taken as a standard and all the other coils were compared with it. They were similarly arranged, side by side, as shown at *1*, *2*, so that any one could readily be connected to the circuit and substituted for the standard coil by throwing over the double-pole double-throw switch *D*. Two storage cells were used; and by adjusting *n* along a suitable resistance *a b*, any desirable voltage could be obtained across the transmitter terminals *c*, *d*.

The primary circuit was adjusted to give, with the standard coil in circuit, as nearly as possible a reading of 3 volts at the terminals of the transmitter and a current of about $\frac{1}{10}$ ampere in the primary circuit, these values being found

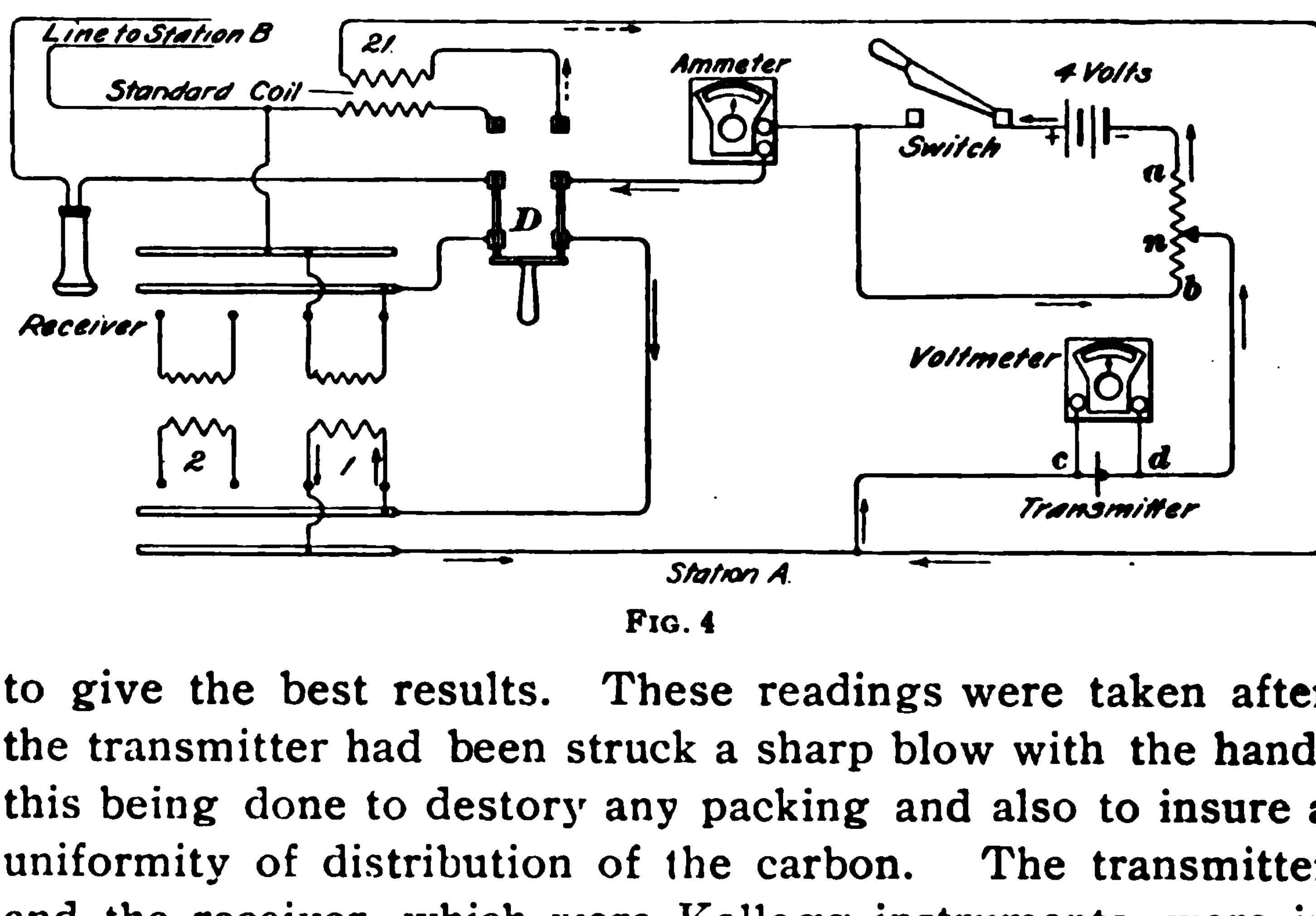


FIG. 4

to give the best results. These readings were taken after the transmitter had been struck a sharp blow with the hand, this being done to destory any packing and also to insure a uniformity of distribution of the carbon. The transmitter and the receiver, which were Kellogg instruments, were in separate rooms, so that the one listening could not possibly hear the one talking, except through the receiver. Each coil was tested on two lines, one of No. 14 B. & S. galvanized-iron wire (57.4 ohms per mile) about 6 miles long, and the other of No. 9 B. & S. galvanized-iron wire (18.1 ohms per mile) about 100 miles long. These were actual overhead line circuits, the tests being made at night when they were not otherwise in use.

16. Test for Loudness.—In the test, it was supposed that the efficiency was made up of two factors—volume and clearness. The volume, or loudness, was determined relatively only, that is, in terms of the standard coil. The two operators making the test are called *A* and *B*. In testing for volume, *A* would say to *B*, for instance "volume on No. *1*" and both would throw their switches *D* so that the standard induction coil No. *21* would be in circuit. *A* then counted "1 2 3 4 5 and 1 2 3 4 5" but at the word "and" *A* and *B* would simultaneously throw their switches *D* so as to cut in No. *1* in place of No. *21*. Thus, *B* would hear the first five numbers through the standard pair and immediately afterwards the second five numbers, with all conditions the same as nearly as possible, through the No. *1* pair of coils. This operation was repeated two or three times, and *B* recorded his judgment of the relative volumes in percentages without informing *A*. The process was then repeated, but this time *B* counted and *A* judged the volume and recorded it. An average of the two records represents very closely the comparative volumes.

17. Test for Clearness.—For the clearness test, eight similar lists of fifty words, letters, or numbers were prepared, similar to the following:

brought	thought	wrought	fought	bought	fraught	caught	ought
1	2	3	4	5	6	7	8
E	D	G	P	B	C	V	fee
28	48	8	38	88	888	68	58

In this way, eight lists were obtained, each of which contained a word similar in sound to words in each of the other lists. Operator *A* used four of the lists and *B* the other four. The lists were written on cards and mixed up. *A* drew cards from a box, one at a time, and read the word written on it into the transmitter and recorded the words on a sheet in the order sent. *B* also recorded in order what he heard. When one list or fifty words was used, the process was repeated with another list; but this time *B* repeated the words and *A* recorded what he heard. The original sent and received

lists were then compared and the percentage of correct words found. The average of these two percentages gives a result very nearly independent of any slight defect of either operator, or any error at either end. In both the volume and the clearance tests, as even a tone of voice as possible was used.

18. Results of Tests.—In Table III, which gives the results of the test, V represents the percentage of the volume compared with the volume of the standard coil No. *21*; C represents the per cent. of clearness, or the per cent. of words received correctly; A, the average of the two results V and C; $A\,S$, the per cent. of efficiency of A for each coil compared with A for the standard coil; $C\,S$, the per cent. of clearness for each coil compared with the standard; and the last column gives the average of the $A\,S$ and $A\,S'$ values, that is, the average efficiency of each coil for the two tests. While the table contains considerable useful information, there is, nevertheless, apparently no relation between the ratio of the number of turns in primary and secondary windings or the dimensions of the coil and the efficiency of speech transmission. However, one point shown by the tests is that the greater the ratio of transformation—that is, the greater the ratio of turns in secondary to turns in primary—the better does the coil work on the longer line; that is, the longer the line, the greater should be the ratio of transformation. This would naturally be expected.

DIMENSIONS OF COILS

Number of Coil	Primary: Number of Turns	Primary: Size of Wire B. & S.	Primary: Resistance	Primary: Inductance	Secondary: Number of Turns	Secondary: Size of Wire B. & S.	Secondary: Resistance	Secondary: Inductance	Ratio of Transformation	Core: Diameter Inches	Core: Length Inches	Core: Size of Iron Wire B. & S.	Core: Thickness of Heads Inches
1	111	22	.392	.0061	5,139	32	157	1.264	46.3	$\frac{1}{2}$	4	18	$\frac{1}{4}$
2	14	22	.14	.0012	2,246	32	70.7	.218	51.5	$\frac{1}{2}$	2	18	$\frac{5}{16}$
3	198	22	.62	.0021	2,164	32	87.9	.315	10.9	$\frac{1}{2}$	2	18	$\frac{1}{4}$
4	80	22	.274	.0034	2,413	32	76.3	.29	30.16	$\frac{1}{2}$	3	18	$\frac{1}{4}$
5	44	22	.099	.0012	2,688	32	79	.268	61	$\frac{3}{8}$	2	18	$\frac{1}{4}$
7	132	22	.364	.00086	2,354	32	82.25	.208	17.8	$\frac{3}{8}$	2	18	$\frac{1}{4}$
8	124	22	.24	.00074	1,240	32	43	.079	10	$\frac{1}{2}$	3	20	$\frac{1}{4}$
9	2,640	32	73.5	.365	4,000	30	134.3	.854	1.5	$\frac{1}{2}$	4	18	$\frac{5}{16}$
10	208	22	.54	.00225	1,400	36 and 32 in parallel	34.8	.739	6.73	$\frac{1}{2}$	4	18	$\frac{5}{16}$
11	400	26	2.08	.00574	1,506	28	13.4	.0812	3.76	$\frac{3}{8}$	4	18	$\frac{1}{4}$
12	228	22	.52	.00174	900	36	58.4	.0345	4	$\frac{3}{8}$	4	18	$\frac{1}{4}$
13	400	26	2.07	.00497	1,241	28	16.3	.0475	3.1	$\frac{3}{8}$	4	20	$\frac{5}{16}$
14	220	22	.481	.0025	5,500	36	420	1.124	25	$\frac{3}{8}$	4	20	$\frac{1}{4}$
15	262	18	.99	.0030	420	22	1.91	.0079	1.6	$\frac{1}{2}$	4	20	$\frac{5}{16}$
16	400	26	2.07	.00525	1,700	28	21	.0962	4.25	$\frac{3}{8}$	4	18	$\frac{1}{4}$
17	1,409	22	25.8	.0400	1,800	26	13.36	.0895	1.27	$\frac{3}{8}$	$6\frac{1}{2}$	20	$\frac{1}{4}$
18	113	22	.393	.0006	554	22	1.71	.014	5	$\frac{1}{2}$	4	18	$\frac{5}{16}$
19	371	28	3.5	.0054	2,503	32	74	.208	6.7	$\frac{3}{8}$	2	18	$\frac{1}{4}$
20	170	22	.56	.0011	2,800	26	26	.399	16	$\frac{1}{4}$	$2\frac{1}{2}$	20	$\frac{1}{8}$
*21	272	20	.35	.0015	2,139	32	32	.0978	7.8	$\frac{1}{4}$	$3\frac{1}{2}$	23	$\frac{3}{8}$
5 G	275	18	.88	.0021	2,934	30	84	278	10.7	$\frac{3}{8}$	$3\frac{1}{2}$	23	$\frac{3}{8}$
5 H	275	18	.88	.0022	3,910	30	217	463	14.2	$\frac{3}{8}$	$3\frac{1}{2}$	23	$\frac{3}{8}$

*Used as standard coil

TABLE III

RESULTS OF TESTS

Number of Coil	6-Mile Line: Voltage Across Transmitter Volts	Current in Primary Circuit Amperes	Volume of Sound V	Clearness of Sound C	C Compared With Standard CS	Average of V and C A	A Compared With Standard AS	106-Mile Line: Voltage Across Transmitter Volts	Current in Primary Circuit Amperes	Volume of Sound V'	Clearness of Sound C'	C Compared With Standard CS'	Average of V and C A'	A' Compared With Standard AS'	Average of AS and AS' for Both Tests
1	2.83	.155	62.5	72	97.5	67.25	77.5	3	.140	163	86	106	124.5	136	106.7
2	2.8	.172	47.5	67	91	57.25	65.7	3	.135	77	59	73	68	75	70.35
3	2.83	.159	100	81	109.5	90.5	104	2.8	.155	110	80	79	95	105	104.5
4	2.8	.157	27.5	67	91	47.25	54.5	2.95	.130	95	81	100	88	97.5	76
5	2.85	.158	40	72	97.5	56	64.5	3	.115	30	28	34.6	29	32	48.25
7	2.8	.165	90	77	104	83.5	96	2.9	.120	105	80	99	92.5	102	99
8	2.9	.163	90	81	109.5	85.5	98.5	2.95	.118	92.5	88	109	90.2	99.8	99.15
9	.95	.040	35	64	86.5	49.5	57	1.05	.040	50	40	49.5	45	49.7	53.37
10	3	.113	100	85	115	92.5	103.2	2.95	.120	102.5	84	104	94	104	103.6
11	2.85	.105	100	75	101.5	87.5	100.5	2.85	.125	72.5	79	97.5	95.8	84	92.25
12	3	.105	80	85	115	82.5	95	3	.122	65	79	97.5	72	79.6	87.3
13	2.95	.100	105	73	98.7	89	102	2.85	.115	82.5	81	100	81.7	90.5	96.25
14	2.97	.120	87.5	68	92	77.75	88.5	3	.120	105	80	99	92.5	102.5	95.5
15	2.97	.107	82.5	79	107	80.75	92.5	3	.127	73	75	92.7	74	82	87.2
16	2.85	.105	110	76	102.5	93	107	2.8	.125	105	66	81.5	85.5	94	100.5
17	1.7	.060	85	67	91	76	87.5	1.5	.070	48	49	60.5	48.5	53.7	70.6
18	3	.113	45	62	83.6	53.5	61.5	3.05	.115	48	67	82.8	57.5	63.6	62.5
19	2.75	.103	100	77	104	88.5	101.5	2.85	.095	105	84	104	94.5	104.5	102.7
20	3	.108	32.5	63	84.3	47.75	54.9	3.05	.085	63	62	85	62.5	69	62
21	3.1	.110	100	74	100	87	100	3.2	.110	100	81	100	90.5	100	100
5 G	3	.110	100	75	101.3	87.5	100.5	3.05	.110	107	69	86	88	97.5	99
5 H	3	.112	102	67	91	84.75	97.6	3.05	.110	115	77	95	96	106	101.8

MAGNET-WINDING CALCULATIONS

19. Coils Designated by Their Resistance.—The resistance of a wire varies directly as its length and inversely as its sectional area, or inversely as the square of its diameter. From this it is evident that the number of turns in a coil, since this varies as the length of the wire, has a definite relation to its resistance, and, therefore, the resistance of a coil may be taken as a measure of the number of turns of wire it contains. It is easy to measure the resistance of a finished coil, but it is not an easy matter to determine the number of turns or the length of wire used. On account, therefore, of this practical convenience, and not because the resistance itself is a desirable quantity, it is customary to speak of an electromagnet or coil as having a certain resistance instead of a certain number of turns, and, therefore, to designate it by its resistance.

20. If a given space is filled with a winding of insulated wire, the resistance of the whole coil will be approximately proportional to the square of the number of turns of wire. Furthermore, the number of turns of insulated wire that can be put in a given space will be approximately inversely proportional to the square of the diameter over the wire and its insulation. For, if a given spool, wound full of wire, is rewound with another wire of one-half the cross-section, the spool will contain twice the number of turns, and, therefore, twice the length of wire. But the resistance per unit length of the second wire is twice that of the first. Therefore, since the spool contains twice the length of wire, each unit length of which has twice the resistance of the first, the total resistance of the spool rewound with the smaller wire will be four times as great as it was originally. That is, doubling the number of turns and using a wire of one-half the cross-section quadruples the resistance. Hence, the resistance

varies as the square of the number of turns. Even if exactly the same space is occupied in each case, this is only approximately true.

This may be summarized in the following manner:

Let R = resistance;

T = number of turns;

d = diameter (bare) of wire with which given spool is filled;

d_x = diameter of wire over the insulation;

If this same spool is refilled with a wire whose bare diameter is d' and diameter over insulation d_x', the resistance R' and the number of turns T' will have such values that the following formulas will be approximately satisfied:

$$\frac{R}{R'} = \frac{(T)^2}{(T')^2} \qquad (1)$$

that is, the resistance is directly proportional to the square of the number of turns.

$$\frac{T}{T'} = \frac{(d_x')^2}{(d_x)^2} \qquad (2)$$

that is, the number of turns is inversely proportional to the square of the diameter of the wire over its insulation.

If the bare diameter of a wire is doubled, the area will be four times as great and the resistance one-fourth as great for the same length; but only one-fourth as many turns of the larger size wire can be put in the same space (neglecting insulation on wire), hence the length of the larger wire will be one-fourth that of the smaller wire and its resistance per unit length only one-fourth as great, and its resistance will be only one-fourth of one-fourth, or one-sixteenth, as great. Hence, if the diameter varies from 1 to 2, the resistance will vary from 16 to 1, but 16 = 2^4, hence the resistance varies inversely as the fourth power of the diameter. Therefore,

$$\frac{R}{R'} = \frac{(d')^4}{(d)^4} \qquad (3)$$

that is, the resistance is inversely proportional to the fourth power of the diameter of the bare wire.

If the ampere-turns are kept constant, then

$$\frac{I'}{I} = \frac{T}{T'} \qquad (4)$$

in which I and I' are the currents necessary with T and T' turns, respectively. From formulas **2** and **4**, it is evident that

$$\frac{I'}{I} = \frac{(d_x')^2}{(d_x)^2} \qquad (5)$$

and from formulas **1** and **4**, that

$$\frac{(I')^2}{(I)^2} = \frac{R}{R'} \qquad (6)$$

Hence, the current varies inversely, formula **4**, as the number of turns, directly, formula **5**, as the square of the diamater of the wire over its insulation, and inversely, formula **6**, as the square root of the resistance. The above formulas will not give very accurate results because the wire is seldom wound on a spool in a perfectly uniform manner.

21. The diameter of a copper wire, in inches, that will fill a bobbin or spool of given dimensions and offer a given resistance can be found approximately by the following formula:

$$d = .0288 \sqrt[4]{\frac{l(d_o^2 - d_1^2)}{R}}$$

in which d = diameter of bare copper wire;
l = length of winding space on spool;
d_o = outside diameter of coil;
d_1 = inside diameter of coil, and generally, in telephone magnets, practically the same as diameter of iron core (the above must all be expressed in inches);
R = resistance of coil, in ohms.

In electromagnets having two coils, R is the resistance of one coil only.

NOTE.—The total number of turns in a coil is equal to the cross-section of the coil, normal to the direction of the wires, in square inches, multiplied by the number of wires that can cross a square inch. This may be written as follows: number of turns = number of square inches × wires per square inch. The total length of wire is evidently the

total number of turns multiplied by the mean length of one turn. The mean length of one turn $= \frac{\pi}{2} \times (d_o + d_1)$. Hence, the total length of wire in the coil = number of square inches × wires per square inch $\times \frac{\pi}{2} \times (d_o + d_1)$. The cross-section of the coil in square inches $= \frac{l \times (d_o - d_1)}{2}$, in which l is the length of the coil; and the number of wires per square inch $= \frac{1}{d_x^2}$, approximately, in which d_x is the diameter, in inches, of the wire over its insulating cover. Then the total length of wire in the coil $= \frac{l \times (d_o - d_1) \times \pi \times (d_o + d_1)}{2 \times 2 \times d_x^2}$. Now, a copper wire $\frac{1}{1000}$ inch in diameter and 1 foot long has a resistance of 10.5 ohms (international ohms at 75° F., or 24° C.); hence, a copper wire 1 inch in diameter and 1 inch long will have a resistance of $\frac{10.5}{12 \times (1{,}000)^2}$ ohms, and a copper wire having a diameter of d inches will have a resistance of $\frac{10.5}{12 \times (1{,}000)^2 \times d^2}$ ohms per inch of length. Then, for the total resistance R of the wire in the coil, we get $R = \frac{l(d_o - d_1) \times \pi(d_o + d_1) \times 10.5}{4 \times d_x^2 \times 12 \times (1{,}000)^2 \times d^2}$. In order to reduce this to a convenient form, it is necessary to make the approximation that $d_x = d$. This is not a very serious error, especially in this case, where some of the other quantities may not be very exact, and the error reduces as the wire increases in size. Making this approximation, simplifying, and solving for d, we get

$$d = \sqrt[4]{\frac{10.5 \times \pi \times l(d_o^2 - d_1^2)}{4 \times 12 \times (1{,}000)^2 \times R}}, \text{ or } d = .0288 \sqrt[4]{\frac{l(d_o^2 - d_1^2)}{R}} \text{ inches.}$$

After calculating d, the size of the wire that has this diameter may be obtained from a wire table. In order to allow for irregularities in winding, insulation, etc., the next smaller gauge wire should be used, because a length of the smaller wire having the required resistance will not quite fill the space, while, for the next larger size of wire, the spool would not hold enough of the wire to produce the desired resistance, or, strictly speaking, there would not be enough turns.

DIMENSIONS OF MAGNET WIRES

22. Wire used for winding magnets is usually insulated with one or more wrappings of cotton or silk. The thickness of the insulation varies slightly with different makes of wire, but the outer diameters, as given in Table IV, may be taken as the average for single, double, and triple cotton-covered

wires. In this table, the quantities are not carried to more than three significant figures. The values so obtained are accurate enough for most calculations connected with magnet windings. On this account, the values in the second, third, and fourth columns differ somewhat from those given in standard wire tables. The column headed Wires per Inch gives the number of insulated wires that can be placed side by side in a space of 1 inch; these numbers are useful in estimating the number of turns that can be wound per layer in a winding space of given axial length. The column headed Wires per Square Inch gives the number of turns that can be placed in each square inch cross-section of winding space. The wires per inch and per square inch are, if anything, on the lower side, and there should be no difficulty in getting the number of wires stated into the specified space.

23. The following expression is often useful for magnet-winding calculations:

$$R = \frac{r \times v}{12 \times d_x^2}$$

in which v = volume, in cubic inches, of the space to be occupied by the coil;

r = ohms per foot;

d_x = diameter over insulation of size wire to be used;

R = total resistance of whole coil.

For any size wire, r and d_x can be obtained from tables; then, if either R or v is known, the other can be determined.

NOTE.—Evidently, $\frac{r}{12}$ is the resistance per inch. The volume occupied by a given length of wire is equal to its cross-section multiplied by its length and, hence, the volume v divided by the cross-section of the wire gives the length of wire. If the wire is wound on a spool, the area occupied by each wire will be approximately equal to the square of the diameter, and not to $\frac{\pi d_x^2}{4}$, because, when the wires are piled over and alongside one another, each wire occupies nearly a square, each side of which is equal to the diameter of the wire, and the intervening spaces in each corner of each square are almost unoccupied and lost. Hence, the volume divided by the square of the diameter gives the approximate total length of wire. Therefore, the total length $\frac{v}{d_x^2}$, in inches, multiplied by $\frac{r}{12}$, the resistance of the wire

TABLE IV

MAGNET WIRE

No. B. & S. Gauge	Bare Wire			Single Cotton-Covered Wire			Double Cotton-Covered Wire			Triple Cotton-Covered Wire			Single Silk-Covered Wire	Double Silk-Covered Wire
	Diameter Mils d	Area Circular Mils Square of Diameter	Area Square Mils $(.7854\, d^2)$	Diameter d_x Over Insulation Mils	Wires per Inch $\frac{1{,}000}{d_x}$	Wires per Square Inch $\left(\frac{1{,}000}{d_x}\right)^2$	Diameter d_x Over Insulation Mils	Wires per Inch $\frac{1{,}000}{d_x}$	Wires per Square Inch $\left(\frac{1{,}000}{d_x}\right)^2$	Diameter d_x Over Insulation Mils	Wires per Inch $\frac{1{,}000}{d_x}$	Wires per Square Inch $\left(\frac{1{,}000}{d_x}\right)^2$	Diameter Over Insulation Mils	Diameter Over Insulation Mils
0000	460	212,000	166,000							478	2.09	4.36		
000	410	168,000	132,000							428	2.33	5.42		
00	365	133,000	105,000							383	2.61	6.81		
0	325	106,000	82,900				339	2.94	8.64	343	2.91	8.46		
1	289	83,700	65,700				303	3.30	10.8	307	3.25	10.5		
2	258	66,400	52,100				272	3.67	13.4	276	3.62	13.1		
3	229	52,600	41,300				242	4.13	17.0	247	4.04	16.3		
4	204	41,700	32,800	211	4.73	22.3	216	4.62	21.3	220	4.54	20.6		
5	182	33,100	26,000	189	5.29	27.9	194	5.15	26.5	198	5.05	25.5		
6	162	26,300	20,600	169	5.91	34.9	174	5.74	32.9	178	5.61	31.4		
7	144	20,800	16,400	151	6.62	43.8	156	6.41	41.0	160	6.25	39.0		
8	128	16,500	13,000	136	7.35	54.0	141	7.09	50.2	145	6.89	47.4		
9	114	13,100	10,300	121	8.26	68.2	126	7.93	62.8	130	7.69	59.1		
10	102	10,400	8,150	108	9.25	85.5	112	8.92	79.5	116	8.02	64.3		
11	90.7	8,230	6,470	97	10.3	106	101	9.90	98.0	105	9.52	90.6		
12	80.8	6,530	5,130	87	11.4	129	91	10.9	118.	95	10.5	110		

13	71.9	5,180	4,070	78	12.8	163	82	12.1	146	86	11.6	134		
14	64.1	4,110	3,230	70	14.2	201	74	13.5	182	78	12.8	163		
15	57.1	3,260	2,560	63	15.8	249	67	14.9	222	71	14.0	196		
16	50.8	2,580	2,030	56	17.8	316	59	16.9	285	63	15.8	249	52.8	54.8
17	45.3	2,050	1,610	50	20.0	400	53	18.8	353	57	17.5	306	47.3	49.3
18	40.3	1,620	1,280	45	22.2	492	48	20.8	432	52	19.2	368	42.3	44.3
19	35.9	1,290	1,010	39	25.6	655	43	23.2	538	47	21.2	449	37.9	39.9
20	32.0	1,020	802	36	27.7	767	40	25.0	625	44	22.7	515	34.0	36.0
21	28.5	810	636	32.5	30.7	942	36.5	27.3	745	40.5	24.6	605	30.5	32.5
22	25.3	642	505	29.0	34.4	1,180	33.0	30.3	918	37.	27.0	729	27.3	29.3
23	22.6	510	400	26.6	37.5	1,400	30.6	32.6	1,060	34.6	28.9	835	24.6	26.6
24	20.1	404	317	24.1	41.4	1,710	28.1	35.5	1,260	32.1	31.1	967	22.1	24.1
25	17.9	320	252	21.9	45.6	2,070	25.9	38.6	1,480				19.9	21.9
26	15.9	254	200	19.9	50.2	2,520	23.9	41.8	1,740				17.9	19.9
27	14.2	202	158	18.2	54.9	3,010	22.2	45.0	2,020				16.2	18.2
28	12.6	160	126	16.6	60.2	3,620	20.6	48.5	2,350				14.1	16.6
29	11.3	127	100	15.3	65.3	4,260	19.3	51.8	2,680				13.8	15.8
30	10.0	101	78.9	14.0	71.4	5,090	18.0	55.5	3,080				12.0	14.0
31	8.93	79.7	62.6	12.9	77.5	6,000	16.9	59.1	3,490				10.9	12.9
32	7.95	63.2	49.6	11.9	84.0	7,050	15.9	62.8	3,940				9.95	12.0
33	7.08	50.1	39.4	11.1	90.0	8,100	15.1	66.2	4,380				9.08	11.1
34	6.31	39.8	31.2	10.3	97.0	9,400	14.3	69.9	4,880				8.31	10.3
35	5.62	31.5	24.8	9.6	104	10,800	13.6	73.5	5,400				7.62	9.62
36	5.00	25.0	19.6	8.5	117	13,600	12.0	83.3	6,930				7.00	9.00
37	4.45	19.8	15.6										6.45	8.45
38	3.97	15.7	12.3										5.97	7.97
39	3.53	12.5	9.79										5.53	7.53
40	3.15	9.89	7.76										5.15	7.15

per inch, gives the total resistance of all the wire on the spool, that is, the resistance of the coil.

EXAMPLE.—How many turns of No. 20 double cotton-covered wire can be wound in eight layers on a spool having a length, inside the end shoulders, of 1.25 inches, assuming that the wires are wound evenly so that no space is lost between turns?

SOLUTION.—The diameter of No. 20 double cotton-covered wire, from Table IV, is 40 mils, or .04 inch. Hence, there will be $\frac{1.25}{.04}$ turns in one layer and $\frac{1.25 \times 8}{.04} = 250$ turns in the eight layers. Ans.

TABLE V

DATA ON DOUBLE SILK-COVERED COPPER WIRE

B. & S. Gauge Number	o = Ohms per Cubic Inch	u	Pounds per Cubic Inch
20	.76	.79	.24
22	2	.69	.23
24	5	.62	.21
26	12	.55	.19
28	25	.49	.17
30	54	.43	.14
32	105	.37	.12
34	195	.31	.08
36	355	.25	.075
38	630	.19	.06
40	1,050	.13	.05

24. Table V, taken from the Physical Laboratory Notes of the Massachusetts Institute of Technology, gives the ohms o per cubic inch for some sizes of double silk-covered copper wire. By *ohms per cubic inch* is meant the number of ohms of a given size of insulated copper wire that can be put in a space of 1 cubic inch. It is not calculated by any formula, but is based on data obtained by winding a few actual coils. The column headed u gives the ratio of the volume of the copper to the total volume of the coils as actually wound, and the last column enables one to determine the weight of wire necessary for a coil when the volume

is known. As the wire becomes smaller, the insulation on it occupies a larger proportion of the total volume. For instance, a spool filled with No. 40 has only 13 per cent. of its volume occupied with copper.

USEFUL FORMULAS

25. The following formulas may prove useful under different conditions: All dimensions, such as length of spool, diameter of wires, etc. must be expressed in inches. The derivation of these formulas is not of sufficient importance to be given here.

The resistance R, in ohms at 75° F., of a given coil may be calculated by the following formula, provided that we have given the outside diameter of the coil d_o, the inside diameter of the coil d_1, the length of the coil l, the diameter of the bare copper wire d, and the diameter of the wire over its insulation d_x:

$$R = \frac{.0000006872\, l(d_o^2 - d_1^2)}{d_x^2\, d^2}$$

26. In this or almost any other formula, any quantity in the formula may be calculated, if all the other quantities are known. For instance

$$d_o = \sqrt{\frac{R\, d_x^2\, d^2}{.0000006872\, l} + d_1^2}$$

EXAMPLE.—If a coil, having a length of 1 inch, inside diameter .4 inch, and outside diameter of 1 inch, is wound with No. 28 double silk-covered copper wire, what will be the resistance of the coil?

SOLUTION.— .0126 is the diameter of the bare wire and .0166 the diameter of the wire over its double-silk insulation. By substituting in the formula given in Art. 25, we get

$$R = \frac{.0000006872 \times 1 \times (1^2 - .4^2)}{(.0166)^2 \times (.0126)^2} = 13.2 \text{ ohms. Ans.}$$

27. To find the bare diameter d of a wire for a spool having an inside diameter d_1 and an outside diameter d_o that will produce a given number of ampere-turns IT with a given voltage E, the following formula may be used:

$$d = \sqrt{\frac{.000001374\,(d_o + d_1)\, I\, T}{E}}$$

EXAMPLE.—What will be the number of ampere-turns in a coil whose inside diameter is $\frac{3}{8}$ inch and outside diameter $\frac{7}{8}$ inch, when wound with No. 33 B. & S. single cotton-covered copper wire and having a difference of potential of 8.5 volts across its terminals?

SOLUTION.—From Table IV, the diameter of No. 33 B. & S. wire is 7.08 mils or .00708 inch. By solving the formula for the ampere-turns IT, and then substituting the quantities given, we get:

$$IT = \frac{d^2 E}{.000001374(d_o + d_i)} = \frac{(.00708)^2 \times 8.5}{.000001374(\frac{7}{8} + \frac{3}{8})} = \frac{.00005013 \times 8.5}{.000001374 \times 1\frac{1}{4}}$$
$$= 248 \text{ ampere-turns. Ans.}$$

28. If either the length l or the depth of winding $\frac{d_o - d_i}{2}$ is known, the other may be calculated from the formula:

$$l = \frac{2\,T d_x^2}{d_o - d_i}$$

in which T = number of turns;
d_x = diameter of wire over its insulation.

29. Heating Effect.—When a current flows through a coil, it continues to get hotter and hotter until the amount of heat radiated from the surface of the coil is just equal to the heat being produced in the coil. The inside of a coil will be hotter than the outside, and a thick coil tends to get hotter than a thin one. It is generally safe to design a coil so that it will have a sufficient cylindrical surface to radiate 1 watt per square inch of this surface when the temperature of the coil is 100° F. above that of the surrounding air. Hence, the watts ($I^2 R$) produced in the coil should not exceed, for a rise in temperature of 100° F., about 1 watt per square inch of cylindrical surface.

30. In practice, the radiation from the ends of the coil and from the core is neglected and all the heat is always supposed to be radiated from the cylindrical surface. This is on the safe side and simplifies the calculations. A magnet should usually be so designed that it will stand, indefinitely, the full voltage of the circuit without overheating; then it will not be damaged should a short circuit occur that allows an unusually large current to flow through it. The watts W,

radiated per square inch from the cylindrical surface of a round coil may be calculated from the formula:

$$W_s = \frac{W}{3.1416\, d_o\, l}$$

in which W is the energy expended in the coil in watts and is equal to IE, or I^2R, or $\frac{E^2}{R}$ watts.

31. By substituting $\frac{E^2}{R}$ for W in the last formula and solving for R we get

$$R = \frac{E^2}{3.1416\, d_o\, l\, W_s} \qquad (1)$$

in which R is the warm resistance of a coil having an outside diameter d_o and length l for a given voltage E across its terminals and a given number of watts W_s radiated per square inch.

To obtain the resistance at the temperature of the room, allowance must be made for the difference between the temperatures of the room and the coil. The resistance of the coil at any desired temperature $t°$ is:

$$R_t = \frac{E^2}{3.1416\, d_o\, l\, W_s[1 + .00223(t_1 - t)]} \qquad (2)$$

in which t_1 is the temperature of coil (the higher temperature); and t the temperature at which its resistance is desired.

If $t°$ is the rise in temperature of the coil, then evidently $t° = t_1 - t$.

32. The following formula gives the diameter d of a wire that will give the greatest number of ampere-turns with a rise in temperature of $t°$ F.

$$d = \sqrt{\sqrt{\frac{.000002159\,(1 + .00223\, t°)\, d_o\, l^2\, (d_o^2 - d_1^2)\, W_s}{E^2}} + \frac{(d_x - d)^2}{4}} - \frac{d_x - d}{2}$$

in which $d_x - d$ represents twice the thickness of insulation used on the wire and may be obtained from a table by assuming the approximate size of wire.

33. The greatest number of ampere-turns IT that may be obtained in a coil for a given voltage E, a given rise in temperature $t°$ F., and W_s watts radiated per square inch of cylindrical surface, may be calculated from the formula:

$$IT = E\left[\sqrt{\sqrt{\frac{.000002159(1+.00223\,t°)d_0 l^2(d_0^2-d_1^2)W_s}{E^2}}+\frac{(d_x-d)^2}{4}}-\frac{d_x-d}{2}\right]^2 \div .000001374(d_0+d_1)$$

BATTERIES FOR TELEPHONE WORK

GENERAL REQUIREMENTS

34. Voltage.—The electromotive force best adapted for the operation of the ordinary granular-carbon transmitter when connected in a local circuit with the primary winding of an induction is approximately 3 volts, although some transmitters apparently work with a greater efficiency at as high a pressure as 6 volts. The Blake transmitter, however, attains its maximum efficiency with a pressure of less than 2 volts. For the above reasons, the ordinary granular-carbon transmitter is, as a rule, worked with two Leclanché or dry cells placed in series, thus attaining an initial pressure of about 3 volts. The Blake transmitter always worked best with one Leclanché cell, it having been found that it produced a disagreeable humming sound when subjected to a greater electromotive force. The American Bell Telephone Company use in connection with the White solid-back transmitter for long-distance circuits two Fuller cells, thus attaining a pressure of 4 volts. At one time, three such cells were commonly used in connection with this transmitter, but that practice has been largely abandoned, as it is found that two cells give substantially as good results as three.

35. Internal Resistance.—It is desirable that a battery shall have as low an internal resistance as is possible, in order that the total resistance of the local circuit may be

kept low. A high resistance in the battery would not only reduce, by Ohm's law, the amount of current flowing in the local circuit, but would also reduce the ratio that the maximum change in resistance, produced by the transmitter, bears to the total resistance of the circuit.

36. Current.—The current flowing in the primary circuit of a telephone will, of course, depend on the resistance of the circuit, including the transmitter and the primary of the induction coil, and on the electromotive force of the battery. Owing to the peculiar property of carbon of lowering its resistance when heated, the current through a transmitter subjected to a constant electromotive force will gradually increase as the particles of carbon in the transmitter, which form the main resistance in the circuit, become heated. Inasmuch as the voltage of the battery rapidly falls off during the time when the local circuit is closed, its tendency to reduce the current is in part counterbalanced by the fact that the resistance of the circuit is becoming lower, which would, in itself, tend to increase the current. Whether or not the current through a transmitter actually falls off or increases as the transmitter is used depends on the particular transmitter used and on the degree to which the electromotive force of the battery falls off during use.

In general, it may be said that the transmitters having but a single pair of electrodes, of which the Blake is representative, require about $\frac{1}{4}$ ampere, while some granular-carbon transmitters operate well with as high a current as 1 ampere.

37. Recuperative Power.—A telephone battery is subject to rather severe use, especially if the instrument is used frequently during the day. While in use, it is working for from 1 to 5 minutes through a circuit of comparatively low resistance. The ordinary primary cell will, under these circumstances, be affected to a large degree by polarization, which results in a considerable reduction of the electromotive force; and although the resistance of the transmitter

may become lower, due to its heating, this reduction in the electromotive force may cause a decrease in current. During any one period of use, not excessive, however, the resistance of the transmitter falls to such an extent that the current at the end of the period may be as great, or even greater, than at the beginning, notwithstanding the loss of voltage.

If, during the periods of disuse, the battery regains its strength so that at the beginning of the next period of use its voltage is normal, the same cycle of events will be repeated without impairing the efficiency of transmission. On the other hand, if, after a period of disuse, the battery has not regained its normal voltage, it will not be able to send a sufficient current through the transmitter to properly actuate it; for during the period of disuse, the transmitter will have become cold and its resistance therefore correspondingly high. In this case, the battery will probably not be able to send enough current through the transmitter to heat it appreciably, and therefore the resistance of the transmitter will not be lowered. It is thus seen to be of great importance that a battery should possess the power of quickly regaining its strength, or **recuperating**, as it is termed, after it has been subjected to severe use.

38. Other Requirements.—Besides possessing the proper voltage, low internal resistance, capability of working a reasonable length of time without great falling off in electromotive force, and recuperative power, a cell to be suitable for use in a local circuit containing the primary winding of an ordinary telephone induction coil and an ordinary granular-carbon transmitter should possess the following features: It should be clean and be free from the production of noxious fumes or gases and the creeping of salts, and the fluid should be of such a nature as to produce a minimum amount of damage when spilled; the electrolyte should be of such a nature as not to freeze at ordinary temperatures, for it is frequently necessary to install telephones in positions where the temperature may fall very low; the cells should

be as free as possible from local action, so that while the external circuit is open, there may be no waste of material, because the useless consumption of material makes the operation of the cell expensive, not only on account of the cost of this material, but also on account of the frequent visits of an inspector; it should use materials that are inexpensive, and should be of such a nature as to be readily replenished when necessary, and should not require too frequent attention or renewal of solutions or parts.

BATTERIES FOR TRANSMITTERS

39. The Leclanché Cell.—The cells of the Leclanché type have been found satisfactory for supplying current in the local circuits of ordinary telephones, not because they fulfil all the requirements mentioned, but because they meet more of them than probably any other class of cell, excepting perhaps a good dry cell. They possess to a high degree the recuperative power so desirable, and also have a reasonably high electromotive force, usually about 1.4 volts.

40. Life of Leclanché Batteries.—Under fair circumstances, a good cell of Leclanché battery should last at least 6 months, with no other attention than the occasional addition of water to supply the loss by evaporation. This length of time, however, is frequently greatly exceeded, and where the service is not very severe, cells frequently last several years.

41. Renewal of Batteries.—When a Leclanché cell fails to show the proper voltage, the first step to be taken, if the connections are found to be all right and the zinc in good condition, is to pour out the solution, thoroughly wash off the carbon and the zinc, preferably in hot water, and then fill in with a new solution containing not more than 4 ounces of good, clean sal ammoniac. If the zinc is badly eaten, it should be replaced with a new one. If the cell then fails to show the proper voltage the porous cup, if the cell is of the disk form, should be soaked for several hours in hot water, and then replaced. The probabilities are, however, that a

new porous cup will be required. If the cell has a carbon cylinder containing a solid depolarizer, the carbon cylinder should be unscrewed, the depolarizer poured out, and a new mixture of crushed carbon and manganese dioxide filled in. It is a good plan, however, before putting in the new depolarizer, to soak the carbon cup in hot water for a few hours, as this tends to open its pores by dissolving all soluble matter within them.

When cells having porous cups are used, the latter must be replaced by new ones when the depolarizer is exhausted.

42. Dry cells require no attention until they become exhausted and need to be replaced. Furthermore, dry cells that are fully equal, if not superior, during their intended life, to wet Leclanché cells may now be obtained from reliable dealers. Moreover, they are much cheaper than Leclanché cells. For these reasons, they are now very extensively used in place of wet Leclanché cells. Dry cells that have been made over about 8 months should seldom be accepted, as they gradually dry out and their internal resistance increases even though they have not been used.

43. Fuller Cell.—Batteries composed of two or three Fuller cells have been used with the White solid-back transmitter for long-distance circuits. This cell has the disadvantage of being very unpleasant to handle, on account of the nature of its solutions, and the further disadvantage of producing very serious damage to whatever it happens to be spilled on. It has the advantage, however, of being able to produce a high and constant electromotive force (2.1 volts), and of being able to maintain this voltage for a considerable period when acting through a small resistance. The cell used by the American Bell Telephone Company is termed the Standard Fuller cell.

44. The Storage Battery.—The storage battery, or accumulator, forms an ideal source of current for telephone work, where the proper means for its charging are at hand. The reasons for its adaptability to this work are: first, its high electromotive force, which is practically constant

throughout the entire use of the cell; second, its extremely low internal resistance; and third, its cleanliness. The fumes are disagreeable and destructive, unless confined by a layer of oil over the solution or placed in a properly ventilated room. Storage batteries have not been much used at subscribers' stations because of the trouble in charging them. Several systems have been devised for charging them from a source of current at the central office, during periods when the line is not in use, but there seems to be little prospect of their replacing primary cells in local-battery telephone instruments.

The storage battery is now being used very extensively for supplying current for talking and signaling purposes in the central offices of telephone exchanges, and this use will be considered fully elsewhere.

CONDENSERS

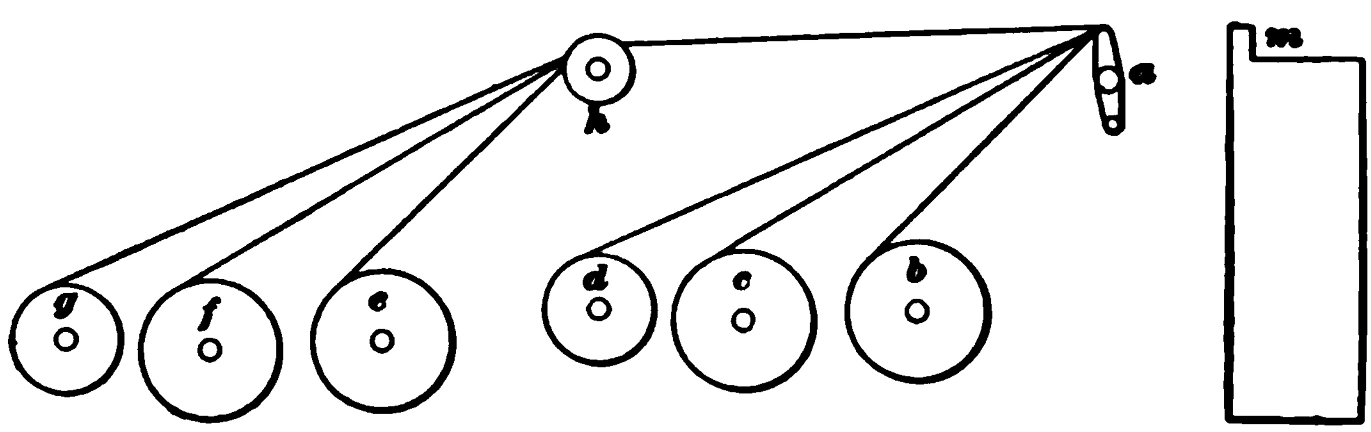
45. The use of **condensers** in telephone systems will be shown in connection with party-line and central-energy circuits; only their construction will be considered at this point.

The capacity of the condenser used in telephone systems does not have to be very accurately adjusted. Condensers of about 2 microfarads are more generally used than any other size. Various methods have been adopted for making condensers. The old way consists in building up the condenser with alternate layers of tin-foil and paper. This is a slow process, however, and a quicker and cheaper method of assembling the paper and tin-foil is now used.

CONSTRUCTION OF CONDENSERS

46. The condensers now used are called **rolled condensers** because the paper and tin-foil come in rolls, or spools, and may be set up in a winding machine. W. A. Taylor gives, in the Electrical Review, the following description of the construction of rolled condensers. In Fig. 5 (*a*), *a* represents a flat mandrel arranged to be turned by means of a crank and on which the paper and tin-foil

are wound. *b* and *c* are rolls of paper; *d*, a spool of tin-foil; *e* and *f*, paper; and *g*, tin-foil. In starting, three or four turns of paper from *b* and *c* are wound around the mandrel. A piece of very thin sheet brass is then wound with several turns of the tin-foil from *d*. The brass is for a terminal connection, and its shape is shown in Fig. 5 (*b*). The little lug *m* extends out of the body of the condenser to form one terminal. The brass piece wrapped in the tin-foil is then laid on the mandrel and a turn is taken. Paper from spools *e* and *f* is then wound once or twice around the mandrel when the tin-foil from spool *g* is started. The paper from spools *e* and *f* and the tin-foil from *g* are passed over the guide spool *h* for convenience in winding. As many turns as necessary are then taken. The tin-foil must be watched



(a) (b)
FIG. 5

closely to see if it becomes torn or runs out of line; it should be about 1 inch narrower than the paper, leaving ½ inch of paper overlapping the foil at each edge to prevent short circuits. When the winding is finished, the tin-foil from *d* is cut first, then the paper from *b* and *c* is cut about 3 or 4 inches longer. The other sheet of tin-foil is then cut about 18 inches shorter than the remaining sheets of paper and another sheet of brass is wrapped into it for a terminal, and there should be several turns of paper over the whole. Two sheets of paper are used between each sheet of tin-foil, because one sheet would be likely to have very small holes, called *pin holes*, in it, which might cause a short circuit. Small particles of metal are also embedded in the paper now and then, which would cause trouble. It is very unlikely that bad places in two sheets of paper will coincide.

A common width for the paper is 8 inches and the tin-foil 7 inches. The thickness of the paper is usually about .0008 inch, while the tin-foil is of various thicknesses from .0003 inch to .0015 inch. It is usual to call all foils used for this purpose by the name, *tin-foil*, although a great deal of it is not by any means tin. Usually the thicker foil is mostly lead, with just enough tin in it to make it roll well. The lead-foil cannot be successfully rolled under .0008 inch, as under that thickness it becomes too flimsy to handle without tearing. It is easier to handle tin-foil at .0003 inch than the lead at .0008 inch. The lead is, of course, much cheaper by weight than the tin, but tin is lighter and a pound covers a much greater surface; consequently, it is found to be much cheaper to use, as it is only the surface that counts.

With the above size of tin-foil and thickness of paper, fifty-six turns make a condenser of approximately 2 microfarads capacity, provided that the condenser is treated in the following manner:

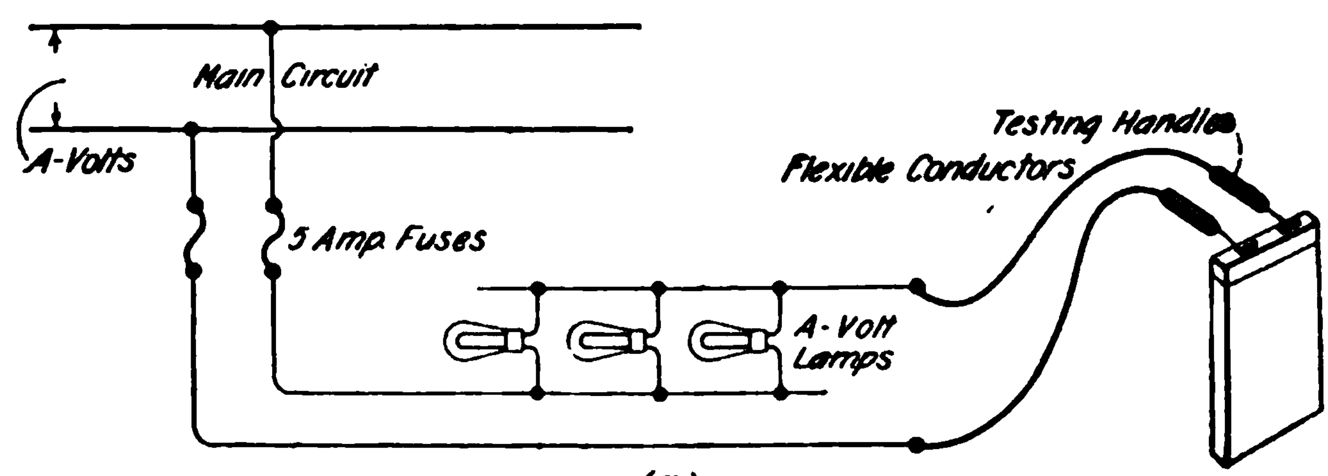
After the condenser is wound it is removed from the mandrel and placed in an oven, where it is heated for a number of hours until it is as dry as possible. Then it is removed and placed in a bath of hot paraffin. This paraffin is heated to a temperature close to 300°F. This heat is sufficient to evaporate all the moisture that may still remain in the condenser. The condenser remains in the paraffin until bubbles no longer arise from it, when it is removed to a press and all the surplus paraffin squeezed out. The condenser remains in the press until cold, when it is removed and is ready for its case.

Such a condenser should have an insulation resistance of not less than 150 megohms, and may run very much higher. Many will test as high as 2,500 megohms. The condenser, when finished, will measure about 8 inches long by 4 inches wide and $\frac{3}{8}$ inch thick. The case used is generally of tinned sheet iron with the connections brought out through insulated bushings on one of the ends. In order to prevent shaking about in the box, paraffin is poured in at a temperature just warm enough to pour. If this paraffin is too hot, it will heat the condenser and cause it to open, thus reducing its capacity.

TESTING CONDENSERS

47. Each manufacturer of condensers, according to Manson, Libby, and Simpson, in the American Telephone Journal, has a certain schedule of tests to which the completed condensers are subjected: first, a *direct-current flash test* for crosses between the terminals, and between the terminals and the case; second, an *alternating-current test* for strength of insulation, sometimes called a "breakdown" test; third, a test for their *electrostatic capacity;* fourth, an *insulation-resistance test.* The tests should be made in this order as the first two tests may render the others unnecessary.

48. The **direct-current flash test** is usually made by connecting a bank of lamps, consisting of several in parallel, in series with the condenser. These lamps should be of the



(a)

FIG. 6

same voltage as the mains across which the circuit containing the condenser and lamps is to be connected. Five-ampere fuses should be placed in each side of the circuit. The lamps and fuses will prevent any serious damage in case there is a short circuit in the condenser. If a testing circuit is connected across a 110-volt circuit, and the terminals of the condenser touched with the testing handles, as shown in Fig. 6, the lighting of the lamps will indicate a cross. The same test applied between the metal case and each terminal in succession will show whether either of the plates is grounded on the case.

49. The most common cause of a short circuit is due to one of the tin-foil plates coming into metallic contact with

another. This can sometimes be removed by mechanically jarring the condensers. If this fails, the flash test may remove it, due to the fact that considerable current flows through the short circuit and burns away the tin-foil at that point, without doing any appreciable damage to the condenser. If the short-circuited condenser is connected across a direct-current circuit, a flash will appear, and, after the short circuit is clear, there will be no further flash on connecting the condenser a second time across the circuit. The flash test is a very convenient method for the repairman to clear short-circuited condensers.

When a condenser is more or less short-circuited due to a puncture, it can sometimes be repaired by heating it with a blow torch until the paraffin inside becomes warm enough to flow around the puncture, and thus separate the two sheets of tin-foil where they have become connected. The heat must not be applied in one place only, as the paraffin may explode if it becomes too hot.

50. The **alternating-current test** consists in applying, in place of the direct current, an alternating current having a frequency of about sixty cycles and an electromotive force of 220 to 400 volts. If this pressure is applied to the terminals of the condenser for about a minute, any weak places in the insulation that are liable to give trouble in the future, will usually be broken down and the plates will become permanently crossed. If a condenser breaks down and a low resistance cross results, the test lamps in series with the condenser will light to their full brilliancy. If the condensers are in good condition, however, 220 volts will produce less than .15 ampere through a 2-microfarad condenser, which is not sufficient to light the test lamps. In case of a breakdown in the resistance, the impedance of the condenser is reduced to zero, and 220-volt lamps will light to their full brilliancy.

51. Capacity Tests.—Probably the most convenient commercial method for the comparison of the capacities of two condensers is by the use of a simple slide-wire bridge, as shown in Fig. 7, in which H is a buzzer or other interrupting

device and I a repeating or induction coil. By thus applying an alternating or interrupted current between the point e and the contact d, the position of d may be adjusted until a point is found where no sound, or at least a minimum sound, is produced in the receiver R. When this point has been found, we have the proportion $bd : da = \frac{1}{C_1} : \frac{1}{C}$, in which bd and da may be expressed in scale divisions of a uniform slide wire; C and C_1 represent the capacities of the condensers, usually in microfarads. Of course, bd and da may be the resistances of two arms of an ordinary Wheatstone bridge, in which case d would be a fixed point, and the resistances bd and da would be adjusted to give a balance. It will

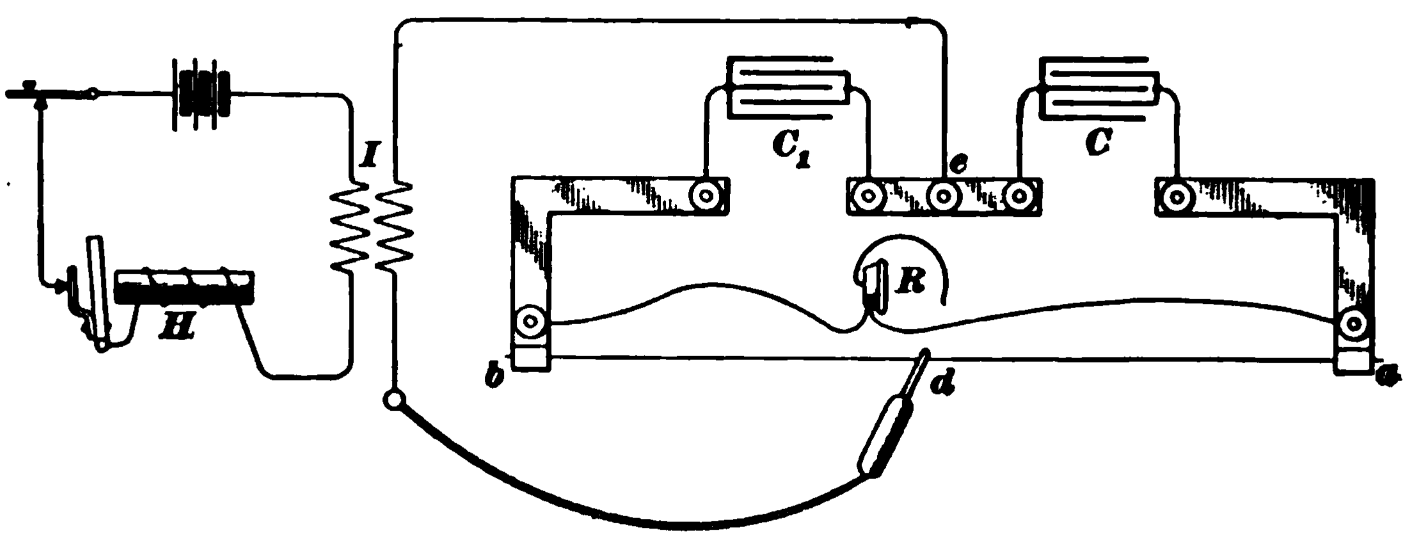


Fig. 7

be noticed that the resistance arms of the bridge are proportional to the reciprocals of the capacities of the condensers, and not directly proportional to the capacities of the condensers. This is due to the fact that the greater the capacity of the condenser the less is its impedance to an alternating current of given frequency. In practice, it is frequently convenient to calibrate the slide wire, so that it will read directly in microfarads. Then, all condensers measuring below a certain acceptable standard are rejected, while those within a reasonable percentage above are passed.

52. The **insulation resistance of a condenser** is usually very high. Commercial telephone condensers are made with insulation resistances from ½ to 50 megohms, according to the use to which the condenser is to be put and

the place allotted to it. An insulation resistance as low as 3.5 megohms will not cause an appreciable loss of current, even if such a condenser is normally connected across the line circuit. The Wheatstone-bridge method may be used for measuring the insulation resistance of condensers up to about 10 megohms, and above that resistance, one of the more sensitive methods explained in *Electrical Measurements* is required.

CALLING APPARATUS

BATTERY CALLS

53. So far, only that apparatus used in the actual transmission of speech has been considered. Although the telephone receiver is capable of making a howling sound, it is customary to provide some other apparatus with each telephone for sending or receiving signals capable of being heard at a considerable distance from the instrument, whereby a party with whom another desires to converse may be brought to the instrument. Inasmuch as telephones are usually supplied with a battery for operating the local transmitter, it would appear at first sight most advantageous to use the energy from this battery for operating the call-receiving instrument at the opposite end of the line. This is, in fact, often done on comparatively short lines, but this method of signaling has certain limitations, which will be pointed out later.

VIBRATING BELLS

54. Construction.—The bell used for battery-call work is usually of the type known as the **vibrating,** or **trembler, bell,** one form of which is shown in Fig. 8. The hammer of this bell is arranged so as to vibrate rapidly back and forth and to strike the gong at each vibration, thus producing a continuous succession of sounds. D, D' are two electromagnets having cores F, F' of soft iron secured to a soft-iron yoke piece Y. G is a soft-iron armature mounted

by means of a flat spring *S* secured to a post *P*, so as to vibrate freely in front of the cores *F*, *F'*. The armature carries a hammer, as shown, adapted to strike the gong a sharp blow when the armature is pulled toward the magnet cores. If the circuit passed directly from one binding post *T* through the coils to the other binding post *T'*, then closing the circuit containing a suitable battery would cause the hammer to strike the gong a single blow. A succession of blows might be produced by rapidly making and breaking the circuit at the point from which the signal was being sent; but this would be an unsatisfactory method. Therefore, the armature of the bell is so arranged as to make and break its own circuit by its vibration. In this way, a rapid and continuous succession of strokes is produced as long as the terminals of the battery are connected to the two binding posts *T*, *T'*. To bring about this result, the circuit between the binding posts of the bell is made as follows: From the binding post *T*, which is insulated from the frame of the bell, a wire leads to one terminal of the coils *D*, *D'*, which are connected together in series. A wire leads from the other terminal of *D'* to the metallic post *N* insulated from the metal framework and provided with a contact screw *M*. While the armature is at rest, a contact spring *X*, carried by the armature, rests against the contact screw *M*, thus carrying the circuit to the armature and the post *P*. This post *P* is connected with the frame of the bell, as is also the post *T'*, so that the circuit from *P* to *T'* is completed through the frame itself. When a current is sent through the coils, the armature will be drawn forwards, thus causing the hammer to

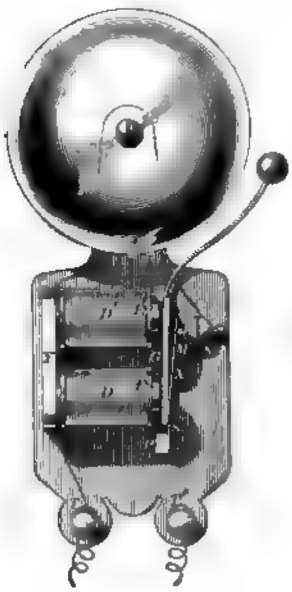


FIG. 8

strike the gong. This movement, however, will break the circuit by causing the spring X to move out of contact with the screw M. This interrupts the flow of current through the coils and allows the armature to spring back, it being no longer attracted by the magnet cores. In doing this, contact is again made between the spring X and the screw M, thus completing the circuit, and again energizing the magnets, thus producing another stroke of the hammer. This process is repeated as long as the circuit is held closed at the sending station. The spring X is provided so that the circuit will not be broken as soon as the armature starts to move toward the cores. Its function is to prolong the time during which the circuit is closed, so as to allow the magnets to exert a pull on the armature until the hammer is almost in contact with the bell.

55. Design.—These bells are manufactured in almost numberless styles, many of which are of exceedingly poor design from both mechanical and electrical standpoints. A good battery bell should be so well constructed that none of its parts are likely to work loose on account of the rapid and violent vibration of the hammer. The point of the screw M and also the surface on the spring X should be tipped with platinum, in order that the surface of the contacts may be kept clean, as platinum will not corrode under ordinary atmospheric conditions, and is, moreover, not affected much by the electric spark, which is sometimes very heavy between these contacts. Silver, being cheaper, is frequently used in place of platinum, and is superior to copper, brass, or iron. The screw M should be provided with a locknut, or with some other means of locking it securely in any position to which it has been adjusted. If this is not done, the vibration of the armature will cause the screw to gradually work back, until finally it reaches a point where the spring X will not make contact with it. This locking is sometimes accomplished by splitting the post N, so that the screw threads in the two halves exert a combined action on the screw, due to the elasticity of the parts of the post.

56. Prevention of Sticking.—Means must be provided for preventing the armature from coming in actual contact with the poles of the electromagnet, as the residual magnetism would cause it to stick and not allow the spring *S* to move it back at once or at all. This may be done in a number of ways, one of which is to secure a thin strip of copper to the surface of the armature that would come in contact with the poles. Another way is to insert a small pin of brass or copper in the ends of the poles in such manner that they project slightly beyond the pole surfaces. Either of these methods should prevent actual contact between the iron surfaces, and therefore eliminate the tendency to stick. This tendency is particularly great where the magnets and armature are not of the best quality of soft annealed iron, because the harder iron retains its residual magnetism with more tenacity. In a first-class bell, these parts are made of the softest grade of wrought iron, so as to be more readily demagnetized when jarred by the striking of the armature against the cores.

57. Adjustment.—The adjustment of battery bells is a very simple matter, and usually the turning of the screw *M* until it occupies the desired position is all that is required. The best position may be determined by gradually turning it, while the circuit is closed, until the hammer vibrates in such a manner as to produce a succession of hard sharp blows against the gong. If the screw *M* is too far back, the circuit will be opened before the armature has acquired sufficient momentum to carry the hammer forwards to the gong, or it may be so far back as not to allow the circuit to be completed at all. On the other hand, if the screw is too far forwards, the spring *X* will not be pulled away, and the circuit will not be broken at all, or else the break will occupy such a short space of time that the hammer will not be allowed to recede far enough to strike a proper blow on the gong. If the adjustment by means of the screw *M* does not produce the desired results, it may be that the armature *G* does not occupy a proper position with respect to the poles

of the magnet. When the hammer rests against the gong, the distance between the armature and each of the pole pieces should be approximately the same. This adjustment may, as a rule, be made by bending the spring *S* slightly, or by shifting the positions of the magnets themselves.

58. Sometimes the surface of the gong against which the hammer strikes does not occupy such a position as to allow the hammer to strike it at the proper moment. If the gong in Fig. 8 is too far to the right, the hammer will strike before the armature has moved far enough toward the pole pieces to allow them to attain their maximum pull. If the gong is too far to the left, the armature will strike the pole pieces before the hammer strikes the gong; in either case a loss of efficiency will result. This may be remedied by

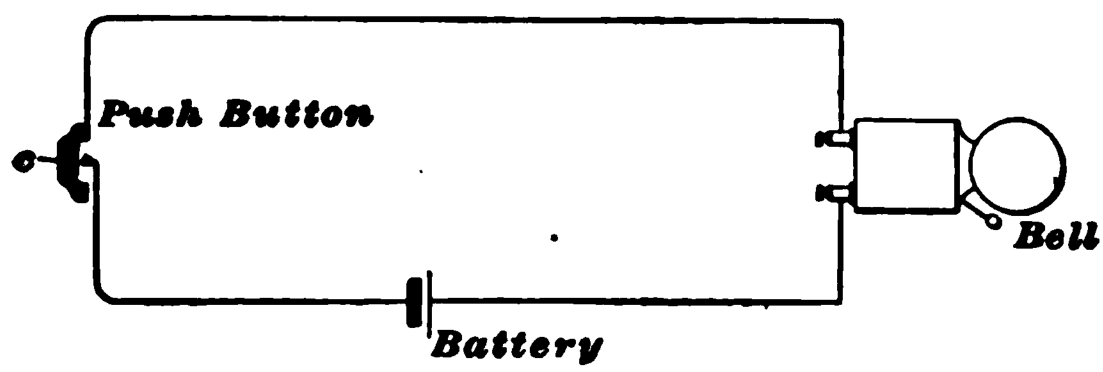


FIG. 9

bending the rod on which the hammer is mounted, but in many cases a better way is to turn or move the gong itself on its standard. They are usually somewhat eccentric, due to imperfections in their manufacture, and therefore by turning them, the surface against which the hammer strikes may be brought into the correct position.

59. Fig. 9 shows such a bell connected in circuit with a battery and push button. By pushing the button, the circuit is closed at *c*, thus allowing the action already described to take place. This circuit is such as would be used for an ordinary push-button call for almost any purpose. In order to prevent the running of separate wires for the telephone circuit and for the calling circuit, special arrangements of circuits are made, which will be described in their proper place.

60. Loud Ringing Battery Bell.—A loud ringing bell made by the Holtzer-Cabot Electric Company, and suitable for extension bells, and fire and burglar alarms is shown in Fig. 10. It is operated by a local battery in about the same manner as any battery bell except that another electromagnet is used in place of a retracting spring. It is called a **bi-gong bell** because it has two gongs, whereas most battery bells have only one gong. There are two electromagnets, the circuits through which are controlled by insu-

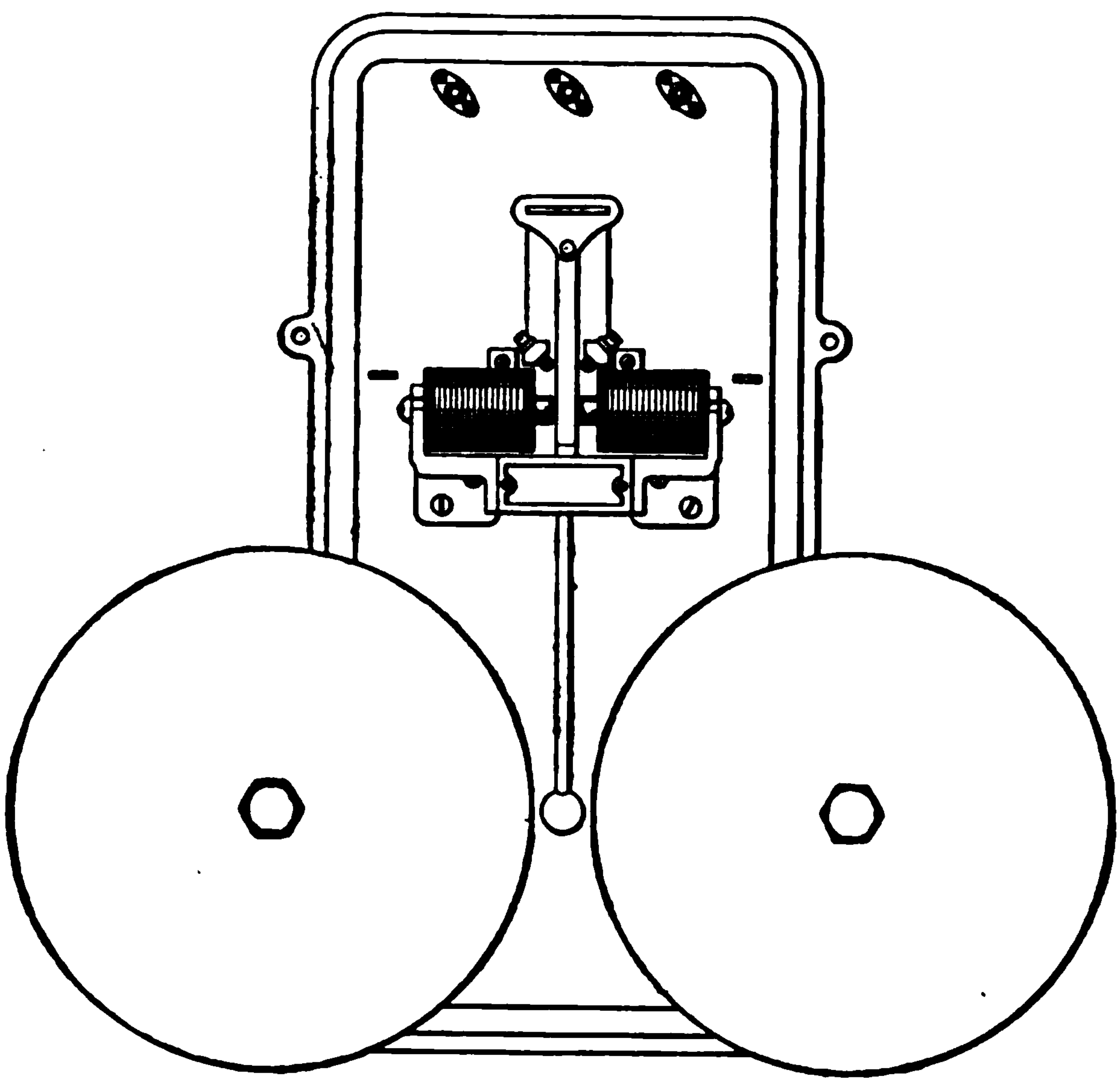


FIG. 10

lated contacts on the armature. The circuit is maintained through one magnet until the armature approaches to within $\frac{1}{32}$ inch of its pole piece, when it is reestablished through the other magnet. The momentum of the heavy hammer causes it to complete its swing and hit one gong; the rebound of the hammer and the pull on the armature in the opposite direction cause it to strike the other gong. The contacts are platinum and the operating mechanism is enclosed in a weather-proof case, except for an opening of less than $\frac{1}{100}$ inch to allow for the movement of the hammer rod.

LIMITATIONS OF THE BATTERY CALL

61. Except for very short lines, the system of calling by means of a vibrating bell—using the transmitter battery for producing the necessary current—has proved a failure. The vibrating bell is not a very sensitive instrument, and for operation over long lines, a considerable amount of battery power is required; it has therefore been found impracticable to successfully operate them without the use of a far greater number of cells than would be required for the mere operation of the transmitter. Moreover, the batteries are subject to a somewhat severe use in supplying current to the transmitters, because the transmitter circuit is usually of very low resistance, and may be left closed for a considerable time and at frequent intervals. Several attempts have been made to successfully operate bells by means of a current induced in the secondary winding of an induction coil, by rapidly making and breaking the primary circuit in which was connected the transmitter battery. By this means almost any desired voltage may be obtained; but the current is correspondingly reduced, and to such an extent as not to be able to produce the desired effect on the bells.

62. Battery Call in Telephone Exchanges.—The remarks in the preceding articles concerning the poor working of the battery bell in telephone work does not apply to all means of calling using battery current. In some of the most improved telephone exchanges, the signal from the subscriber to the central office is given by means of current derived from a battery, and systems based on this plan of operation are proving so successful that there is a probability of their almost universal adoption. In these, however, the signaling is not done by means of a bell, but by means of a sensitive relay, and the battery, instead of being located at the subscriber's station, is usually placed at the central office. Primary batteries are also used for signaling purposes in house and small hotel systems.

MAGNETO-GENERATORS AND BELLS

MAGNETO CALLING APPARATUS

1. The deficiencies in the system of calling by means of the battery bell were recognized at a very early date in the art of telephony, and as a remedy, the **magneto-generator** and **polarized call bell** were produced. The magneto-generator is, in fact, a very simple form of dynamo, capable of generating an alternating current of a moderately high voltage and with a sufficiently large current to accomplish the desired results. The polarized call bell, or ringer, as it is now commonly termed, in order to respond to these currents, is made of a peculiar construction, and requires very much less current than an ordinary battery bell. The magneto-generator and polarized bell are usually mounted in a single box, and have always been so closely associated with each other that it is customary to speak of the two, when mounted together, as a magneto-bell, or, more commonly, as a magneto.

There are two kinds of generators in use—the series and the bridging. These generators differ only in the quantity of current produced.

THEORY OF THE MAGNETO-GENERATOR

2. Law of Electromagnetic Induction.—The action of the magneto-generator depends directly on a law of electromagnetic induction. One way of stating this law is, that if the number of lines of force passing through a coil of wire is varied, an electromotive force will be set up in the coil,

the intensity of which will depend on the rate at which the lines are varied, and the direction of which will depend on the direction of the lines and whether their number is being increased or diminished. One way of varying the number of lines through a coil is to pass a variable current through another coil wound on the same core, as in an ordinary induction coil. Any changes in the strength of the current in the primary, cause corresponding changes in the strength of the magnetic field, which, by the law just stated, produce electromotive forces in the secondary coil. Another way of changing the number of lines of force passing through a coil is to move an electromagnet or a permanent magnet in the vicinity of the coil. Still another way is to move the coil with respect to the magnet; and it is by this method that the magneto-generator is made to produce electromotive forces, and, therefore, when the circuit is closed, corresponding currents.

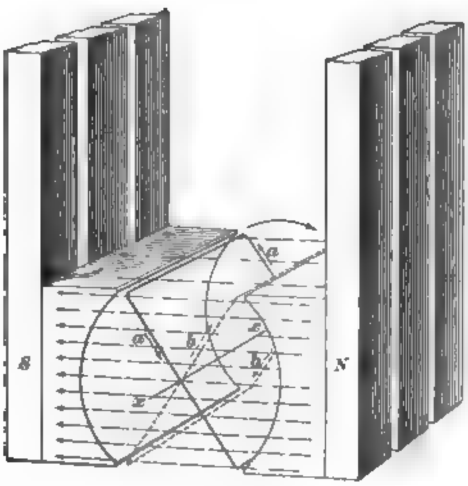


FIG. 1

3. Induction in Revolving Loop.—In Fig. 1 is shown a closed loop of wire that may be revolved about a horizontal axis $x\,x$ within the field of a set of three permanent magnets N, S. The lines of force are indicated by the horizontal arrows, their direction being from the north pole to the south pole according to the usual conception of their flow. The rotation of the loop about the axis $x\,x$ in the direction of the curved arrow may be given by any suitable means.

When the loop is in its horizontal position, it will lie in a

plane parallel to the lines of force, and therefore will include none of the lines. As it is turned into the position shown by the full lines, it will include more and more of the lines of force, and therefore will have an electromotive force and a corresponding current set up in it in the direction of the arrows a, a. When the coil reaches its vertical position, it will include all the lines of force, and from that point on, the number of lines through the coil will be in the same direction, but will be decreasing. Therefore, the direction of the current through the coil will change after passing the vertical position, and the flow of current will then be indicated by the direction of the arrows b, b.

4. If the coil is revolving at a constant speed, the rate of change of the lines of force through the coil will be very slow as it approaches and recedes from its vertical position, being zero when the plane of the coil is at right angles to the direction of the lines of force, and therefore the induced electromotive force is here zero. As the coil approaches its horizontal position, the rate at which the number of lines through it is changing will increase, and the electromotive force will therefore correspondingly increase, although the actual number is more and more rapidly being reduced to zero. When the coil reaches its horizontal position, the electromotive force in it will be a maximum because the rate of change of the lines of force is a maximum, although the number threading through the coil is zero. At that point, the number of lines passing through the coil again begins to increase; this would produce a change in the direction of the electromotive force were it not for the fact that the direction of the lines through the coil relative to the plane of the coil also changes. The electromotive force is therefore at a maximum at the horizontal position of the coil, because the rate of change of the lines through the coil at that point is a maximum. As the coil again approaches its vertical position, the rate of change becomes less and less, and as it reaches that position, no change takes place, and the electromotive force therefore becomes zero. From this point on to the

starting point, the number of lines decreasing; therefore, again producing an electromotive force in the opposite direction, which becomes a maximum as the horizontal position is reached.

5. Graphic Representation of Generator Current. The flow of the current to and fro in the coil may be represented by a sine curve, such as is shown in Fig. 2, the distances above or below the horizontal axis being made proportional to the instantaneous values of the current or the electromotive force, whichever the curve is considered to represent. Assuming the curve in Fig. 2 to be an electromotive-force curve, the point *A* on it corresponds to the vertical position of the loop in Fig. 1. At this point no electromotive force is set up in the loop, and therefore the point *A* is on the horizontal axis of the curve. As the loop rotates on its axis, the electromotive force gradually increases until it lies in a horizontal plane, where the electromotive force is a maximum because the lines of force are then being cut by the loop at a maximum rate. This condition is represented by the point *B* on the curve where the ordinate representing the electromotive force is a maximum. From the horizontal position of the loop in Fig. 1, the electromotive force remains in the same direction, but decreases until the coil again reaches a vertical position, when it becomes zero; this is represented by the point *C* on the curve. At this point, the direction of the electromotive force changes and the curve passes below the horizontal line, and during the next half revolution of the loop, while approaching the second horizontal position, the changes are of the same nature, but in an opposite direction, the electromotive force reaching a maximum in this direction at the point *D* corresponding to the second horizontal position of

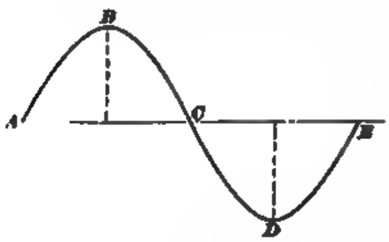


FIG. 2

the loop, and again decreasing to zero, as shown at E, when the loop is at the same vertical position from which it started. A complete revolution of the coil, therefore, produces one complete cycle of changes in the electromotive force and in the current, as represented by the curve $ABCDE$.

6. Construction of Armature.—Instead of having but a single turn of wire, as in the loop shown in Fig. 1, a coil consisting of a great number of turns is used in practice, so that the electromotive force generated in each turn may be added to that of all the others. Furthermore, in order that the greatest possible number of lines of force may flow

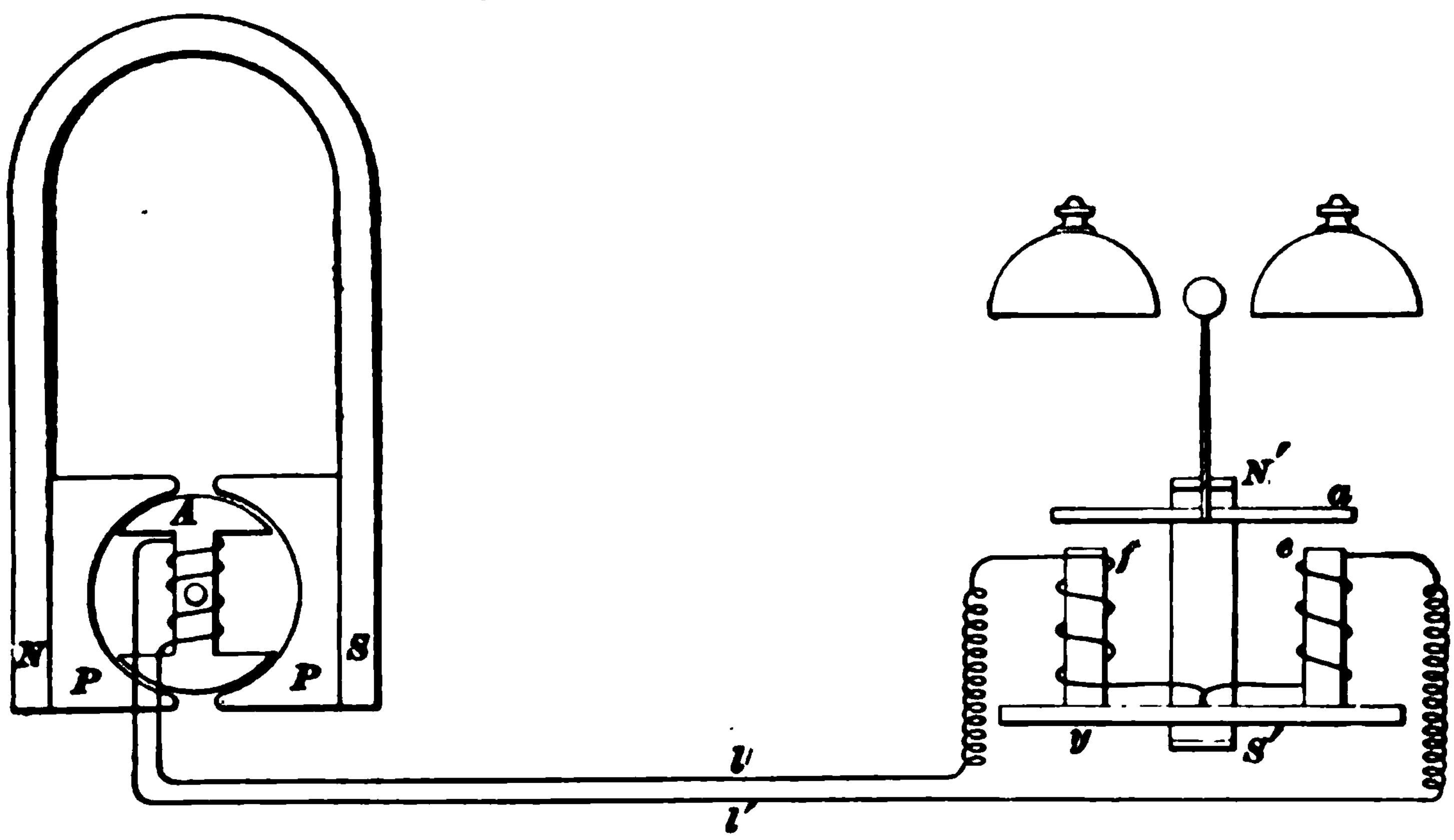


FIG. 3

between the magnet poles and through the coil, the coil is wound on a core of soft iron adapted to fit closely between curved polar extensions or pole pieces of iron secured to the poles of the permanent magnets. Such a construction is shown diagrammatically in the left-hand portion of Fig. 3. In this, A represents the armature core of iron adapted to rotate within the space formed by the iron pole pieces P, P, secured to the poles of the permanent magnet NS. Around the shank of the armature core, in a longitudinal groove provided for the purpose, the coil of insulated wire is wound. This coil entirely fills the space provided by this groove,

although it is represented in this figure, for the sake of clearness, as consisting only of four turns.

7. Generator Shunts.—It is found desirable, for reasons that will be made clearer later, to provide a path of low resistance around the armature coil at all times when the generator is not in actual use. The simplest way of accomplishing this is by means of a push button that normally maintains a closed circuit between the two terminals leading from the generator. If the generator is operated without pressing the push button, the current from the armature flows through the short circuit between the two terminals and does not pass through the external circuit at all. In order to provide against this, the push button must be pressed while the generator is operated, so as to remove the presence of the short circuit. There are several reasons why it is desirable to have this shunt around the armature. It may save the armature coil from being burned out by heavy currents that come in over the line, due to lightning or other causes. However, the chief reason for its use is to provide a path of low resistance around the armature when the generator is not being used.

The opening of the shunt, which is necessary while the generator is being used, may be accomplished by a push button as explained above, but it is a decided disadvantage to add to the number of operations that the user of a telephone must voluntarily perform, and therefore it is far better to provide some means whereby the shunt will be broken automatically by the turning of the crank. This is accomplished in a variety of ways, and a different kind of shunt is usually provided with each commercial type of generator. These will be described in connection with the generators to which they belong. Shunts used with series generators operate to accomplish substantially the same electrical results as the push button explained above. Bridging generators, for reasons that will be explained, are provided with similar automatic devices, but they are arranged to open the armature circuit instead of short-circuiting it.

THEORY OF THE POLARIZED BELL

8. Construction.—The polarized bell, or ringer, is a device adapted to respond to the alternate currents produced by a magneto generator. It is shown in diagram in the right-hand portion of Fig. 3, in which *e* and *f* are soft-iron cores connected by a yoke piece *y* of similar material. Around these cores are wrapped coils of insulated wire in opposite directions, as shown. The armature *a* is also of soft iron, and is pivoted at its center so that its ends may be attracted or repelled by changes in the magnetism of the cores *e*, *f*. This armature carries a hammer adapted to strike alternately against two small gongs as it vibrates to and fro. *N S* is a permanent magnet so placed as to magnetically influence the cores *e*, *f* and the armature *a*. Thus, the middle of the armature *a*, being near the pole *N'* of the permanent magnet, will have south polarity and its ends north polarity, while the upper ends of the cores *e*, *f* will be of the opposite polarity, by virtue of the lines of force from the south pole *S'* passing through the yoke *y* to them. We may thus consider that, normally, the upper extremities of the cores *e*, *f* are south poles, while both ends of the armature *a* are north poles. Under normal conditions, therefore, one end or the other of the armature *a* will be held in contact with one or the other of the poles *e*, *f*, according to which one happens to be the nearer.

9. Action of Currents in Either Direction.—If a current in one direction passes through the circuit of the coils, it will affect the cores *e*, *f* in opposite manners; that is, if it is of such a direction as to tend to make the upper end of the core *f* a north pole, it will tend to make the upper end of the core *e* a south pole—this, by virtue of the fact that the current passes around the two cores in opposite directions. If the current is in the reverse direction, it will tend to make the upper end of the core *f* of negative or south polarity and the upper pole of *e* of positive or north polarity. Inasmuch as the upper ends of the cores *e*, *f* are both normally

negatively polarized, a current in the former direction will tend to strengthen the pole *e* by adding to its negative polarity, while it will correspondingly weaken or reverse the pole *f* by neutralizing more or less of its negative polarity, because the current tends to make it positive. This will cause the end *a* of the armature to be attracted by the pole *e* with greater intensity than the other end is attracted by the core *f*, and will, therefore, cause the hammer to strike the right-hand gong. The current in the opposite direction will strengthen the pole *f* by adding to its negative polarity, and will weaken the pole *e* by neutralizing its polarity by the positive polarity set up by the current. The armature will therefore be attracted by the core *f*, and the hammer will strike the left-hand gong.

10. Action of Alternating Currents.—Since the currents generated by the magneto-generator are alternating in character, flowing first in one direction and then in the other, it is obvious that a positive impulse of current from the generator will, in flowing through the coils of the polarized bell, cause its armature to move in one direction, while a negative impulse of current will cause the armature to move in the opposite direction. Inasmuch as positive and negative impulses follow each other in rapid succession, the armature of the bell is caused to vibrate in unison with them, thus producing the well-known sound of the telephone bell.

MAGNETO-GENERATORS

DETAILS OF GENERATOR CONSTRUCTION

11. Magnets.—The size of bar used for making permanent magnets varies with different makes of magneto, but probably the following are the most common dimensions: $\frac{3}{8}$ by $\frac{3}{4}$, $\frac{3}{8}$ by $1\frac{1}{2}$, and $\frac{1}{4}$ by $1\frac{3}{4}$ inches. The $\frac{3}{8}$ by $1\frac{1}{2}$ inches is used the most. It is the general practice to make the magnets about 5 inches high; anything shorter is bad practice. Even with the above height, a strong current is likely to demagnetize

the generator. The greater the output, in ampere-turns, the greater is the danger of demagnetization, and especially so if the machine is a power-driven generator, which is apt to have short circuits and other heavy loads thrown on it. Some claim that the magnet should be three times as high as it is wide between poles.

The steel for this purpose is subject to the same requirements as that for permanent magnets of receivers; but inasmuch as the cross-section of a bar is, in the case of generators, considerably larger, a somewhat higher carbon steel is frequently necessary. This is so because the larger cross-section of the bar will not allow it to cool so quickly, and therefore, if a very low carbon steel were chosen, it would not attain sufficient hardness for proper magnetization. The steel used by some manufacturers is of such a quality as to allow it to be bent while cold in a suitable forming machine;

FIG. 4

and where this is the case, it is not only cheaper, but better to do so, as an additional heating of the steel is thereby saved. If arrangements are convenient, some claim that it is better to bend the magnets while hot and chill them in one heat, and thus save a large amount of power and also expense for a heavy bending press.

12. Tempering.—The manner of holding the bar to be tempered is shown in Fig. 4. *A* is a block placed between the limbs of the horseshoe after it is heated to a cherry red for tempering, and against which the limbs are clamped by the jaws of the tongs *B* used for holding the bar to be tempered. The object of the block is to insure the setting of the steel in the proper form, as, without its use, the inside distance between the limbs would be either too great or too small after the bar was cold.

In order that the cold water into which the bar is dipped may get at as much of the surface of the bar as possible, the block *A*, which is shown in detail in Fig. 5, is of skeleton form, being built up of two steel side pieces *a*, *a*, held apart by shouldered rods *b*, *b*. The side pieces *a*, *a* are drilled full of holes and made as thin as possible, in order to allow the water to come in contact with the steel as much as possible. For the same purpose, the jaws of the tongs are corrugated in such a manner that the actual contact between them and the surface of the steel is very small. It is highly essential that the water shall be cold, and therefore it is necessary, where a large number of pieces are to be tempered, that it be constantly changing, as otherwise the repeated immersion of the hot bars would cause it to become too warm for efficient service.

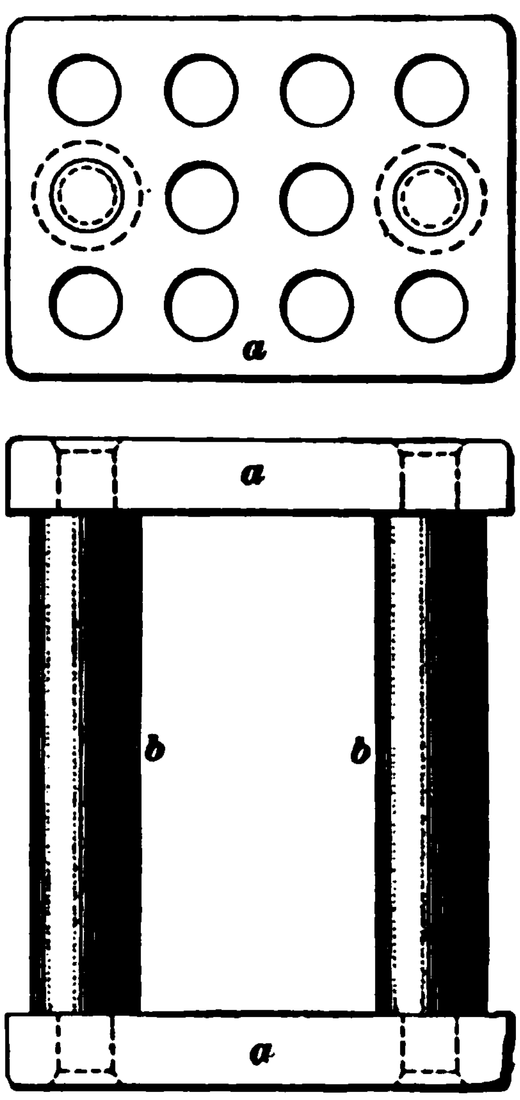


FIG. 5

13. Inasmuch as any mechanical shock tends to lessen the permanent magnetism of a bar of steel, it is highly important that no such operations as grinding on an emery wheel be performed on the bar after it is magnetized. It not infrequently happens that the magnetization is seriously impaired by makers grinding the surfaces of their magnets for the purposes of nickel plating, or for other reasons, after they have been magnetized. All such operations, as grinding, buffing, and nickel or copper plating, if performed at all, should be done before the bars are magnetized. After magnetization, a keeper should be kept on all magnets until they are ready to be put on the generator. Or they may be placed upright on an iron plate or in pairs with the north pole of one against the south pole of the other, and kept that way until used.

It is always best to have the poles at the front of the generator of the same polarity for all machines, and to have all windings connected the same, for if there is ever an occasion to convert the machine into a direct or pulsating generator, the polarity of the current in each will be the same. Uniform polarity of pulsating generators is especially necessary where biased bells, the use and construction of which will be explained later, are to be rung.

14. Armatures.—A common form of armature core made of cast iron is that shown in Fig. 6. Armatures with such cores are capable of producing good results, provided that the proper attention is given to the quality of iron used in the cores. Also, in casting, great care should be taken that

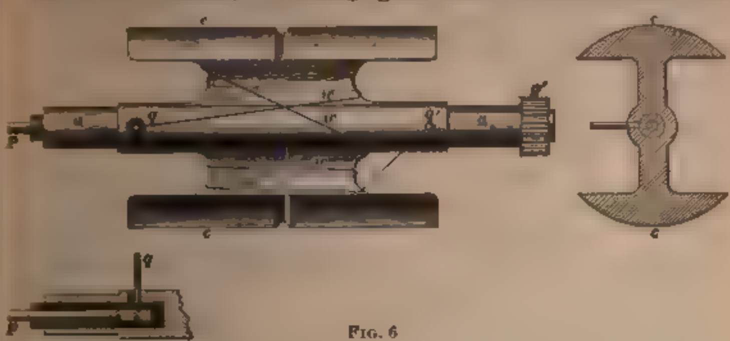


Fig. 6

only the softest grades of iron are used and that the castings do not become chilled in pouring. This latter condition is somewhat difficult to comply with, inasmuch as it is very hard to pour such small castings without chilling them in parts.

The armature core is now generally made of soft metal, either of Norway iron or of very mild open-hearth steel. The usual practice is to make up the armature core of a number of punchings of the latter material. These punchings or laminations are slipped over the shaft and fastened securely to it. The armature cores could be made of cast steel, but they would be more expensive to work up. So it is as much a matter of shop economy to use the built-up core as it is an electrical necessity.

15. Laminated Cores.—An armature provided with a laminated core, that is, one built up of thin layers of soft sheet iron or steel follows closely the principles that have been found of the greatest advantage in the construction of dynamos and motors. Fig. 7 shows one of these armature cores, manufactured by the Holtzer-Cabot Company. In this, the various layers of which the core is formed are stamped from a very soft quality of sheet iron, and are then placed on a spindle of steel and clamped in position by nuts, as shown. In the middle, it is usually customary to place one lamination a little smaller in diameter ($\frac{1}{16}$ inch) than the others, so that a binding string may be tied around the groove so formed to keep the wire on the armature from flying out against the pole pieces when the armature revolves. The spindle on which the laminations are clamped forms the shaft of the armature, which is of the same general form when completed as the cast-iron armatures already described.

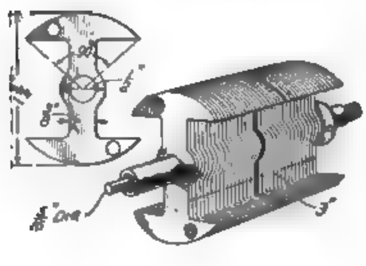


FIG. 7

By this construction, not only is a far better grade of iron, having high permeability and low hysteresis, used in the armature core, but the formation of what are termed *eddy currents* is prevented. These **eddy currents** are currents set up in the core of an armature by the same inductive action that causes the currents to flow in the wire of the armature itself. If the core is of solid cast iron, it is evident that a complete circuit may be formed in it in the same direction as that formed by the wire in the winding. This circuit will be acted on by the changes in the magnetic lines of force passing through it, in exactly the same manner as the circuit formed by the wire, and therefore currents of greater or less intensity flow through the core itself. These do no good, and, in fact, are harmful, inasmuch as the energy represented by them is wasted, and inasmuch as their

direction is always such as to oppose the flow of the legitimate currents in the armature winding itself. By laminating the core, these eddy currents are broken up, because the resistance between the various layers of the core is too high. This method of construction is absolutely essential in the building of larger dynamos, but it was a long time before its advantages were appreciated in the construction of magneto-generators.

At present, the tendency in generator construction seems to be to replace the usual continuous one-piece shaft through the armature by steel-shaft projections, attached to either side of the armature core by means of heavy brass disks. This gives a larger cross-section of laminated iron in the core proper, and a larger winding space freer from irregularities than in the continuous-shaft type. It is claimed that more turns of a larger size wire can thus be wound on the armature, which allows a greater output, better insulation, and greater durability.

16. Winding.—Before winding an armature, it is necessary to properly insulate it; this is usually done by wrapping on it a layer of cotton cloth, or paper, impregnated with shellac or an insulating varnish, so that it will adhere to the sides of the winding space. The armature is then secured in a winding machine, usually on a threaded spindle, which engages a hole tapped in the side of the armature for this especial purpose. The wire is then fed on by hand, while the armature is rapidly rotated until the wire space is filled to the desired degree. Care must be taken that the space is not so full that the outside layers of wire are protruding beyond the cheeks of the core, as this will cause the wire to rub against the pole pieces of the generator in turning and soon cause a break in the circuit. After winding, one end of the coil is fastened to the metallic portion of the core itself, usually, by a brass pin or screw, threaded directly into the spindle, and the other end is fastened to the pin *q*, Fig. 6, which is insulated from the core itself, but in metallic contact with the pin *p* projecting from the end of

the spindle. By this construction, the armature winding terminates on one side in the pin *p*, and on the other side in the armature core, and, therefore, in the frame of the generator, with which the core is in metallic contact through the shaft and bearings.

17. The size of wire and number of turns on an armature vary according to the use to which the generator is to be put. For ordinary exchange service, however, the armature is usually wound with No. 36 B. & S. single silk-covered copper wire to a resistance of between 500 and 600 ohms. This is the usual winding for what is known as a 10,000-ohm generator, the significance of which term will be explained later. The winding should not be shellaced, as it will then be nearly impossible to remove it without cutting it out in case it needs repairing.

The armature of a four-bar bridging generator having the dimensions shown in Fig. 7, and which has proved successful, is wound with 1,900 turns of No. 32 B. & S. single silk-covered wire, half the turns on each side of the shaft, and has a resistance of 225 ohms. The armature for a three-bar generator was 1 inch shorter, but had the same number of turns of the same size wire.

One company regularly winds generator armatures having resistances of 70, 125, 240, 400, and 1,100 ohms; these are for generators varying from the ordinary series to the powerful, so-called jumbo, bridging machine, which has five permanent magnets. Five-bar (permanent magnet) generators are extensively used on rural telephone circuits having a large number of instruments on one circuit.

18. Relation Between Current, Turns, and Resistance.—There is a given space on the armature of a generator of given size and no more wire can be wound on it than will fill the space. If the space is properly filled with a certain size wire, a certain electromotive force is obtained when the armature is turned with the usual speed. The current that can be obtained can then be found by dividing the electromotive force generated in the armature (not the

difference of potential across the terminals of the armature) by the total impedance of the circuit, which includes not only the external impedance, but the internal impedance of the armature as well. Of course, this current can also be determined by dividing the difference of potential across the terminals of the armature by the external impedance. This difference of potential is equal to the total electromotive force generated in the armature, less the fall of potential through the armature, which is equal to the current generated, multiplied by the impedance of the armature. Furthermore, in telephone lines, a large current is only required in a comparatively low-impedance line circuit (as in a bridging circuit having a large number of bells in parallel), whereas, a small current is required only in a comparatively high-impedance line circuit (as in a series-circuit having a number of bells in series with the line). For a circuit having a high impedance and requiring a small current, a comparatively high electromotive force must be developed in the armature in order to get even the small current required. Consequently, the armature, in order to give a high enough electromotive force, must have a large number of turns. Since the space on the armature is limited and a large number of turns must be wound in that space, small wire must be used, and, consequently, the armature will have a high resistance. A high resistance is not desirable to be sure, but it cannot always be avoided with the given amount of space on the armature. Moreover, for a circuit containing a number of bells connected in series, the external impedance will be high; hence, the armature resistance may also be high without very appreciably diminishing the strength of the current that can be obtained in such a circuit.

If, on the other hand, we have an external circuit of small impedance and require a larger current, the armature cannot be wound, as before, with a large number of turns of fine wire, because the high resistance of the armature now being an appreciable part of the total impedance of the circuit would prevent the flow of as much current as desired, for with a large current the fall of potential through the

high-resistance armature would be very large, leaving, therefore, too small a difference of potential across the terminals of the armature to give the required current in the external circuit. Consequently, the armature must be wound to a lower resistance, and in order to do so, a larger wire must be used; and if a larger wire is used, so many turns cannot be wound in the same space. Consequently, by winding the armature with a larger wire, a smaller resistance and impedance are obtained and also a smaller electromotive force. However, since the external and internal impedances are both less in this case than in the former case, it may still be possible to obtain with the lower electromotive force, the larger current that is required. If a larger current and the same electromotive force is required, the space on the armature must be greater in order to hold the same number of turns of a larger size wire. This, with perhaps the addition of more or larger magnets, represents the change to be made in passing from a series-generator, which must be capable of ringing a number of low-resistance bells in series with the line, to a bridging generator, which must be capable of ringing a number of high-resistance bells in parallel across the line circuit. With the same voltage, the output, or power, of the generator increases with the current required.

19. For a bridging generator, four magnets are generally used, though some are made using five, and even six, magnets. A four-bar generator may usually be made sufficiently strong to ring all the telephones that can be successfully operated on one line; but a five-bar generator will give better results if it is properly designed. A common practice is to increase the dimensions of the machine only in length, making no increase in the winding space. The same number of turns of the same size wire as is used in the four-bar generator is then wound on the armature core. The magnetic field is increased 25 per cent., which will increase the open-circuit voltage in like amount, but the resistance of the winding has increased 25 per cent. because each turn is 25 per cent. longer. On account of the higher resistance

in the armature, the increase in electromotive force is offset by the increase in the internal drop when the current flows through the generator. Furthermore, if the armature is wound to the same resistance by using a larger wire, there will be 25 per cent. less turns in the same space, and the decrease in electromotive force, due to the reduced number of turns, will just balance the increase in the magnetism due to the extra magnet. What is necessary is to increase the diameter as well as the length of the armature, then a coarser wire may be used and more turns obtained with a less resistance.

The series-generator is nearly always made with three magnets and of the same dimensions as the bridging generator, except that it is made shorter.

20. A good three-magnet generator has an output of about 5 watts and a voltage of 80, when the armature revolves at a speed of 1,500 revolutions per minute. The makers of a good three-bar generator claim that it is not advantageous to wind the armature above 500 ohms because then the resistance increases more rapidly than the electromotive force. The speed cannot be increased because the bell will not respond properly to a higher frequency. A good series generator should be capable of ringing fifty bells of 80 ohms each, when they are connected in series through 5,000 ohms. A series-generator should also ring clearly an 80-ohm bell through 10,000 ohms, and it should not show a loss of over 5 per cent. in its magnetism in the first year; that is, it should still ring the same bell clearly through 9,500 ohms.

A four-magnet generator should ring twenty bells of 1,000 ohms each, connected in parallel, through a resistance of 2,000 ohms. One manufacturing company has a circuit consisting of thirty-six 1,600-ohm bells in parallel with 100 ohms non-inductive resistance in series between every second bell to represent the line resistance. Its three-bar generator will usually ring thirty-two bells. Another test made by the same company is to determine how low a shunt can be connected across a bell without preventing it from ringing. This

company's three-bar generator will ring the bell with a shunt as low as 43 ohms. A five-bar generator used on some party lines will give good service when there are twenty 2,000-ohm bells bridged across the same line circuit.

21. Pole Pieces.—The material of which the pole pieces are made is usually cast iron, although in the many recent types of generators each pole piece is stamped in one piece from a good quality of soft sheet iron. The advantages obtained by using a fine quality of soft iron in the pole pieces are not so great as in the case of the armature core. One reason for this is that the flow of magnetic lines of force through the pole pieces is always in the same direction; while in the armature, the direction of the flow is changed twice during every revolution. Inasmuch as a good quality of iron permits these changes of direction through it with a minimun loss, it follows that it is very essential to use the finest quality of iron in all parts subject to rapid changes in magnetization, while it is not of such great importance, although desirable, in parts where the magnetization is nearly constant.

The use of cast iron for pole pieces enables a very accurate fitting of the pole pieces to the armature itself, for the chamber in which the armature turns may be readily and accurately bored out to the required diameter. This degree of accuracy is somewhat lessened where the pole pieces are stamped from sheet iron, as it has been proved impracticable to obtain as close a fit as where the interior of the pole faces were bored after having been firmly secured together in place. From this, it will be seen that the air gap between the armature core and the pole pieces is necessarily larger in the case of the stamped sheet-iron pole pieces than where the pole pieces are of cast iron; and this feature alone will probably. offset any advantages derived from the better quality of iron used. Still another objection to the use of sheet-iron pole pieces is found in the fact that with ordinary construction it is impossible to obtain as good a magnetic joint between the pole pieces and the inner surfaces of the bar magnets as where cast iron is used.

The ideal construction, where stamped pole pieces are used, would be to conform the surfaces of the magnets themselves to the curved portions of the pole pieces, so that there would be a large area of contact between them.

In a good magneto-generator, constructed with cast-iron pole pieces properly turned and adjusted, it is not practicable to have an air gap of less than $\frac{1}{64}$ inch, and $\frac{1}{50}$ inch is the usual air gap. It is possible to obtain a much smaller air gap than this and still allow a free rotation of the armature, but this is likely to produce friction between the armature and the pole pieces after the bearings become somewhat worn from long use.

22. Bearings.—The bearings for the armature are always subject to a greater amount of work than those for the crank-shaft, because of the fact that the armature usually rotates about five times as fast as the crank. In many of the cheaper generators, the end plates, which form bearings for both the armature and crank-shaft, are stamped from sheet brass varying in thickness from $\frac{1}{16}$ inch to $\frac{1}{8}$ inch. The bearings are formed in these merely by reaming out the holes to the required size. This gives a very small bearing surface, and as a result, the wear is excessive and the generator is soon rendered inoperative, either by the striking of the armature cheeks against the pole pieces or by the failure of the gear-teeth to mesh properly. Where the greater thickness mentioned, that is, $\frac{1}{8}$ inch, is used, however, the generators frequently wear very well, provided that the bearings are properly centered.

A better way, although a more expensive one, of making the bearings, is to insert a bushing of brass into the stamped end plate, the bushing afterwards being reamed out to form the proper bearing surface. This method, or that hereinafter illustrated, in which the end plates are formed of castings made of sufficient thickness to insure a proper bearing surface, is used in many generators. Excellent bearings are now made of hard-drawn brass and are provided with oil holes.

23. Driving.—The usual form of driving mechanism used in generators consists of a large gear-wheel mounted on the crank-shaft, meshing with a comparatively small pinion mounted directly on the armature shaft. One of the most common faults found in generators is due to the fact that the large gear-wheel is cut from very thin sheet brass, and, even though it properly engages the pinion, after a short time wears a rut in it, due to the small area of contact between the teeth and the fact that the teeth on the small pinion make a rubbing contact about five times as often as do the teeth on the larger gear. It has been quite common to make the large gears only $\frac{1}{16}$ inch thick, and many are still constructed in this way; they should be carefully avoided in purchasing. As a remedy against this undue wear between the gears, the thickness of the large gear has been in many cases increased. The gears should be machine cut and the tooth face should be not less than $\frac{1}{4}$ inch wide. In some good generators the small gear is drawn from hard-brass rod; this makes a harder gear than one cut by a machine. The chain drive has been tried, but it is no longer made.

A ratio of 1 to 5 with three revolutions of the handle per second will give about fifteen periods, or cycles, per second, which is a suitable frequency for ringing ordinary polarized bells, although twenty cycles per second is about as good and is extensively used. The ratio between the gear and pinion should be some incommensurable ratio so that the same teeth will not come together at each revolution. For instance, if there are 27 teeth on the pinion and 134 teeth on the large gear, the ratio will be slightly less than 5, and any tooth on the pinion will come in contact with the same tooth on the large gear only once in every 134 revolutions. The pinion should be connected to the armature shaft by means of springs, so that in driving, all the unevenness is taken up by these springs. The springs must be made strong enough so that they will not break, and at the same time they must not be too stiff.

24. Form of Current Wave.—The form of wave approaching most nearly the sine wave, shown in Fig. 2, has been found best suited for signaling over long lines. This is the curve of the current generated by a coil of wire revolving at a uniform rate in a uniform field of force. In the magneto-generator, this form of wave is rarely ever attained, as the relation between the pole faces and the cheeks of the armature core does not give a uniform field of force, and so serves to modify this form of wave to a considerable extent. As has been pointed out, when the center of the armature faces are opposite the center of the pole faces, the current is changing in direction and is therefore passing through zero; at right angles to this position, the current is a maximum. Were it not for the iron of the armature core, the changes in passing from the former position to the latter would be gradual, and the current curve would be approximately that of a simple harmonic wave.

25. Core Cheeks Too Narrow.—If the cheeks of the armature core are not wide enough to fill the gap between the pole faces when the plane of the armature coil is horizontal, the curve will assume the form shown in Fig. 8 (*a*); that is, it will have two distinct humps in every half cycle. These humps may be readily accounted for. During the time that the cheek of the armature core is passing the pole piece, there is but little change in the number of lines of force passing through the armature core, and the current therefore passes through zero as the armature passes through the position where the plane of the coil is vertical. As the corner of the armature cheek recedes from the pole piece, however, there is a distinct rise in electromotive force and current, owing to the fact that the number of lines passing through the armature are rapidly decreasing. This causes the first hump in each half cycle of the curve (*a*). Almost

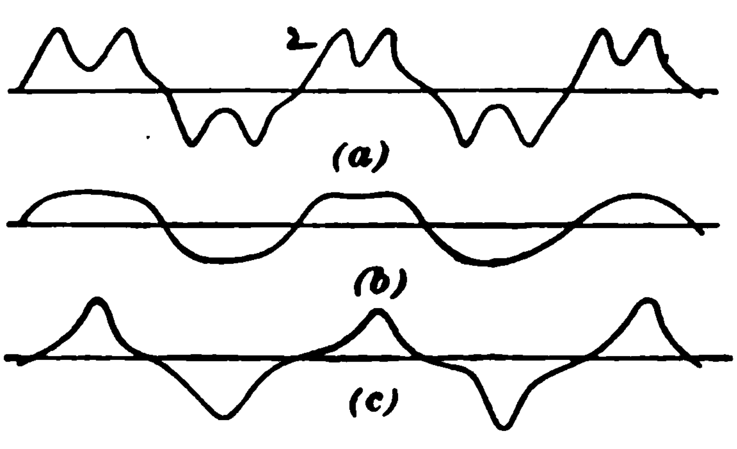


FIG. 8

immediately afterwards, the leading corners of the armature core approach the opposite pole corners, thus causing a great increase in the flow of lines through the core in the opposite direction; this forms the second hump in each half cycle of the curve.

26. Core Cheeks Too Wide.—On the contrary, where the core cheeks are so wide that they overlap the intervals between the pole pieces, the curve form will be flattened, as shown in Fig. 8 (*b*). This is caused by the fact that the changes in the number of lines passing through the armature coil is always gradual. When the armature is in its vertical position, with the two core cheeks bridging across the intervals between the pole faces, a good path is formed for the lines of force through the cheeks without passing through the shank of the core. As the armature rotates, this condition is gradually changed, until the armature is in the position where the plane of the coil is vertical, when all the lines will pass through the armature coil.

27. Proper Width of Core Cheeks.—The best relation between the width of the core cheeks and the distance between the pole pieces is such that each should occupy just 90° of the circumference of the cylindrical space in which the armature rotates; in other words, when the core cheeks will just fill the space between the pole pieces when the armature coil is horizontal, and will just fill the cylindrical portions of the pole pieces when the armature coil is vertical. With this construction, the current curve corresponds very closely to that shown in Fig. 8 (*c*), which, it is true, is not a very close approximation to a simple harmonic curve, but probably the nearest approach that can be obtained in practice with the ordinary form of magneto-generator.

28. Voltage of Generators.—The voltage given out by any magneto-generator depends on the strength of the magnetic field, on the number of turns of wire on the armature, on the speed of rotation of the armature, and to some extent on the relation between the cheeks of the armature

and the pole pieces. At the usual rate of turning by hand, an ordinary machine should generate an electromotive force of from 60 to 80 volts when wound for ordinary service.

On account of the demand for a generator that will ring a large number of telephones on a line, it has become necessary to constantly increase the size and output of the machine. It is not uncommon to find a generator that will ring forty telephones on lines of 12 or 15 miles in length. The magneto-generator is nothing more than a dynamo, and conditions that will apply to one will apply to the other. What is to be obtained is as strong a magnetic field as possible, a large number of turns on the armature, and a low resistance winding.

COMMERCIAL TYPES OF MAGNETO-GENERATORS

29. Early Form of Generator.—In Fig. 9 is shown

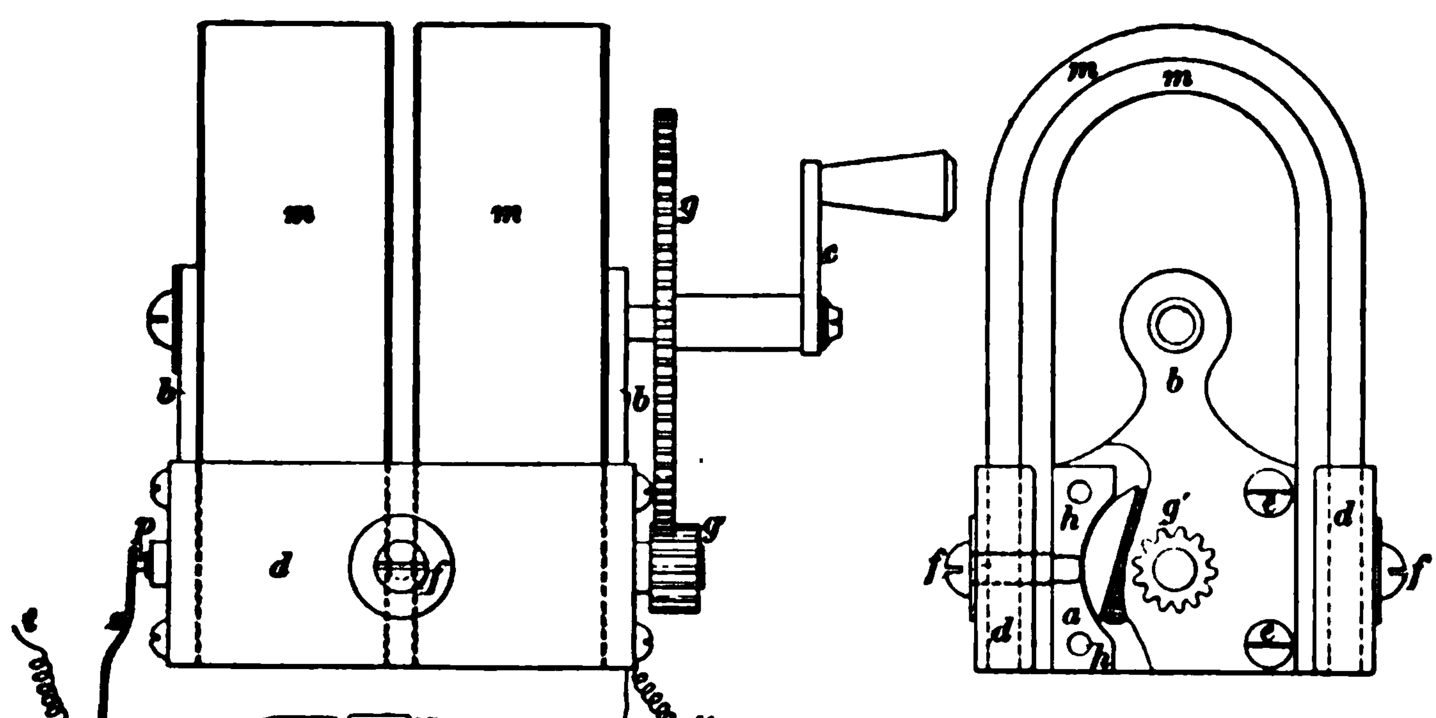


FIG. 9

two views of an early magneto-generator. The pole pieces *a* are of cast iron, having the surfaces that face each other machined into cylindrical form. These pole pieces are held in position by the sheet-brass end plates *b*, which are secured to their ends by screws *e* passing through the end plates themselves and into tapped holes *h* in the pole pieces. The armature core is of cast iron, of a form shown in side and end elevation in Fig. 6. The shaft of the armature, which is

cast as an integral part of the core, is turned in a lathe so as to form suitable bearing surfaces *a*, *a*, Fig. 6, adapted to turn freely within the bearings in the end plates *b*, Fig. 9. The cylindrical surfaces *c c*, Fig. 6, of the armature core are also turned, while on the same centers, to a diameter slightly less than the internal diameter of the cylindrical surfaces of the pole faces, so that the armature may rotate freely when in place.

The armature in generators of this type is usually wound with No. 36 wire to a resistance of about 600 ohms, the wire lying in the space formed between the pole cheeks on the core and the shaft. One end of the armature shaft is bored for the reception of a hard-rubber plug, into which is set a brass pin *p* projecting beyond the end of the shaft. This pin is insulated from the body of the armature, but is in metallic contact with a second insulated pin *q* projecting through a hole bored in the side of the armature spindle and screw-threaded into the pin *p*. This construction is shown in the small detached cut in the left-hand portion of Fig. 6. To this pin *q* is attached one end of the wire forming the armature coil, while the other end is attached to a similar pin q' screwed directly into the metallic shaft. The pin *p*, therefore, forms one terminal of the armature coil, while the shaft itself forms the other terminal. The winding is represented in Fig. 6 by a few turns of wire *w* instead of a large number of turns, in order that the path from the pin *q* to pin q' may be readily traced.

30. A rapid rotary motion may be given to the armature by means of the crank *c*, Fig. 9, through the medium of the large gear-wheel *g* mounted directly on the crank-shaft, which engages a pinion g' mounted directly on the armature shaft. The ratio of the number of teeth on the large gear-wheel to the number on the pinion is usually about 5, so that one revolution of the former produces about five revolutions of the armature. The crank-shaft is journaled in bearings formed in outward extensions of the end-plates *b* on each side of the machine.

The permanent magnets *m* are of horseshoe shape, and four in number; they are clamped in position against the outer faces of the pole pieces by the screws *f* passing through the clamping plates *d*, between the two pair of magnets and into the pole pieces *a*. These magnets are, of course, all arranged with their like poles together, so that the sum of their magnetic effects may be secured.

31. Connections With External Circuit.—In order that the currents generated by the rotation of the armature may be sent over an external circuit for the ringing of bells or other purposes, one wire *t'*, Fig. 9, is attached to the frame of the machine, which is in constant electrical contact with the terminal of the armature winding that is secured directly to the shaft, the connection being through the end plates *b* and the bearings of the armature. Another wire *t*, forming the other terminal of the external circuit, is attached to the spring *s*, which bears with considerable pressure against the end of the pin *p*, which, as has been shown, is in electrical contact with the other terminal of the armature winding.

Across the terminals of the generator is connected the shunt, which is normally held closed by the action of the push button spring. While the generator handle is turned with one hand, the push button *w* must be pressed with a finger of the other hand, thereby opening the shunt circuit.

32. Western Telephone Construction Company's Magneto-Generator.—The form of magneto-generator made by the Western Telephone Construction Company is shown in Fig. 10, in which *M*, *M*, *M* are the permanent magnets, bent from steel, having a cross-sectional area $\frac{3}{8}$ by $\frac{7}{8}$ inch. Before putting on the magnets, the pole pieces between which the armature revolves are firmly riveted together, at a suitable distance apart, by means of shouldered brass rods. The two pole pieces so fastened together are then placed in a boring machine and the cylindrical space, in which the armature is to turn, is carefully bored out. The armature, which is of somewhat greater diameter than in the ordinary

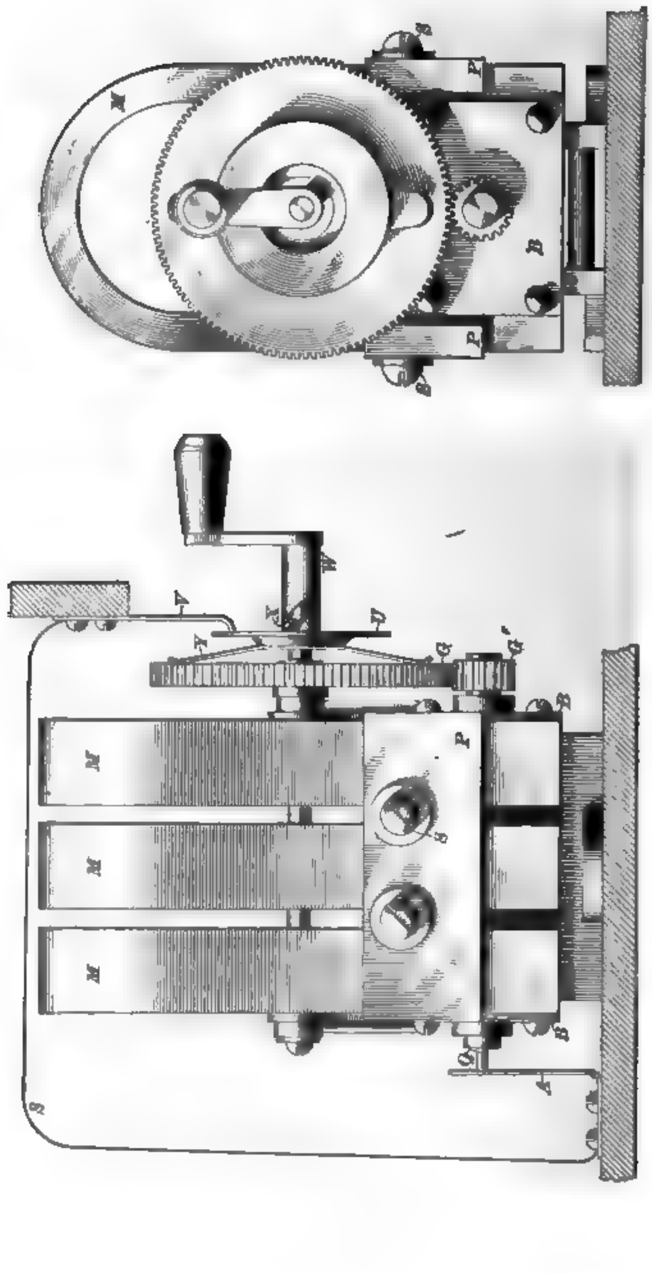


FIG. 10

form of generator, is then put in place, it being journaled in the cast-brass end plates B, B, which are secured to the ends of the pole pieces by screws, as shown. Vertical extensions, a part of the end plates B, form journals for the crank-shaft. The magnets are clamped into position on the pole pieces by screws S, S passing through washers and clamping plates P, P, and then between the magnets, into the pole pieces. Both the large gear G and the pinion G' are cut from cast-brass blanks, the width of the large gear-face being about $\frac{3}{16}$ inch.

33. Generator Shunt.—The automatic shunt of this generator consists of a plate or collar U carried on a brass crank-shaft that is normally pressed toward the right by means of the spring Y, which bears against the large gear-wheel. This plate U is therefore normally pressed against the spring V, secured to the inside of the generator box; this spring is connected by the shunt wire S to the spring A that rests against the armature pin Q. As the pin Q forms one terminal of the armature winding and the frame of the generator the other terminal, the wire S forms a short circuit around the armature, which is only broken when the collar U breaks contact with the spring V. This happens when the crank of the generator is operated, for the slotted sleeve W to which the handle is fastened and which is loosely mounted on the shaft, is automatically pressed toward the generator by means of the pin X riding on the inclined sides of the slot in the sleeve. This presses the collar U away from the spring V before the generator starts to turn, and therefore the shunt is never present while the generator is being operated. As soon as the hand is removed from the crank, the spring Y presses the collar U again into contact with the spring V, thus reestablishing the short circuit.

34. Chain-Driven Generator.—At one time the Holtzer-Cabot Electric Company made a generator with a chain drive, as shown in Fig. 11. The cast-iron pole pieces P, P are accurately bored out to form the armature chamber and

are secured to end plates *A*, *B* by means of the screws *p*. These end plates have on their inner surfaces shoulders corresponding in curvature to the bore of the pole pieces, so that the inner surfaces of the latter when resting against these shoulders are accurately centered. The armature is laminated, and the magnets are clamped in place by short bolts *F*, passing between them and into threaded holes in upwardly projecting parts of the pole pieces. On an upright standard from the end plate *B* is mounted, by means of the bolts *b*, *b*, the crank-bearing *C*, in which the crank-shaft carrying the large gear-wheel rotates. The large and small

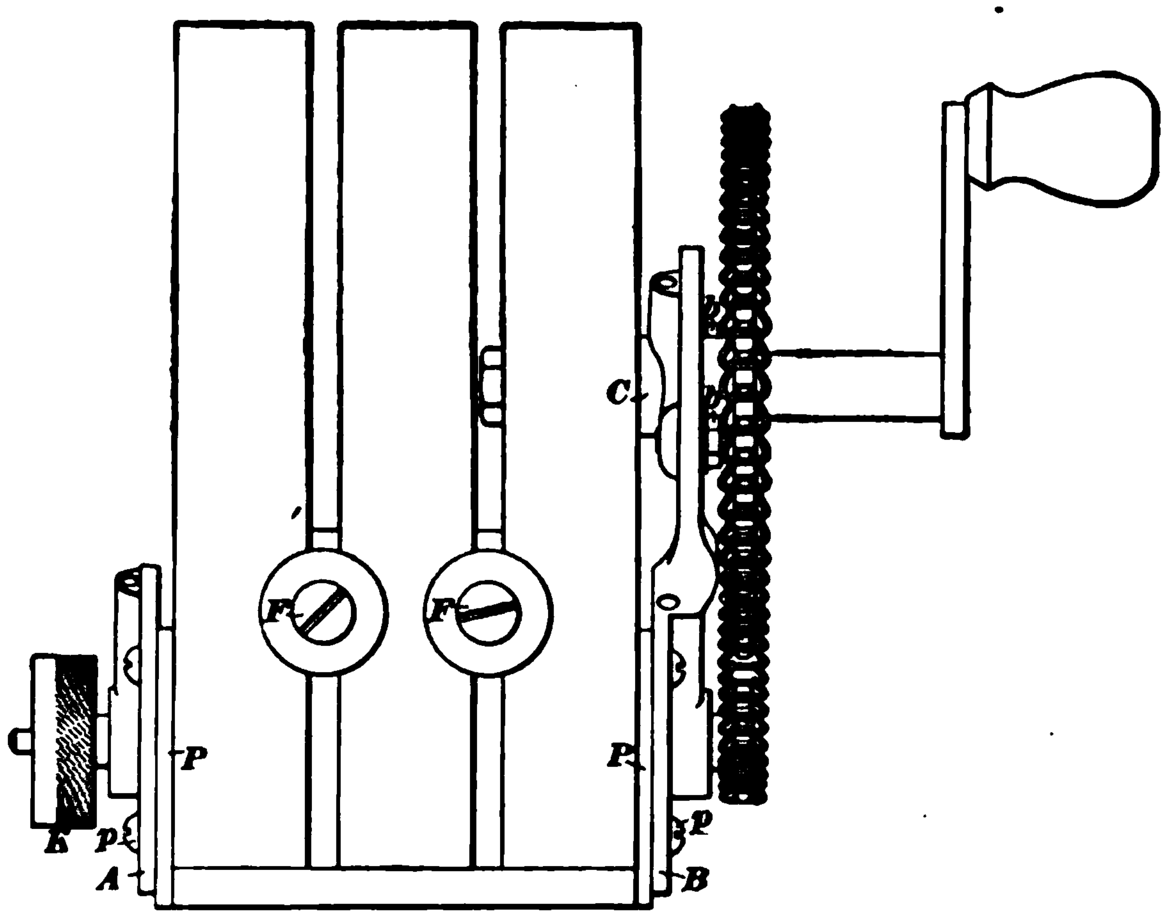


FIG. 11

gears are connected by means of a driving chain of steel links passing over both. The bearing *C* of the crank-shaft may be adjusted, in order to tighten or loosen the chain, by means of the slotted holes through which the bolts *b* pass. This method of driving secures a very smooth-running generator, and where the chain is constructed of such material that it will not stretch, and properly fitted to the gear-wheels, proves satisfactory.

All Holtzer-Cabot generators are now made with gear-wheels in place of the chain, while between the pinion and armature, a flexible connection is secured by means of spiral

compression springs that are inserted in grooves in the pinion, the arrangement being such that it is impossible for the pinion to rotate without moving the armature shaft. By means of this arrangement, a uniform motion of the armature is secured and, as a result, uniform current waves are sent out on the line.

35. Automatic Shunt.—The shunt *K* on the chain-driven generator is very simple. It is shown in detail in Fig. 12, in which *P* is the contact pin projecting from the end of the armature shaft, with which one end of the armature coil is connected. *K* is a cup of thin brass, secured directly to the armature shaft, and is therefore in metallic connection with the other terminal of the armature winding. Occupying about two-thirds of the space within the cup is

FIG. 12

a mass of small metallic particles, formed by clipping No. 20 brass wire into very short lengths. These particles are held in place by a mica washer, through which the pin *P* projects. While at rest, as shown at (*a*), a short circuit is formed around the terminals of the armature by means of the metallic particles, which electrically connect the pin *P* and the cup *K*. As soon however, as the armature is rotated, centrifugal force causes the particles to fly toward the outer portions of the chamber, as shown at (*b*), leaving the portion immediately surrounding the pin *P* entirely empty. This opens the short circuit between the pin *P* and the cup *K*, and therefore breaks the shunt around the armature and allows the current to pass to line.

This type of shunt is no longer made. In its place springs, resembling those shown in Fig. 13 and operated

by a longitudinally moving crank-shaft, are now used on Holtzer-Cabot generators.

36. Kellogg Generator.—The generator made by the Kellogg Switchboard and Supply Company is shown in Fig. 13, with a portion of the magnets cut off so as to better show the frame and gears. The various parts are shown in Fig. 14. The usual continuous one-piece shaft has been replaced by steel-shaft projections attached to either end of the armature core by means of heavy brass disks *v*, *w*,

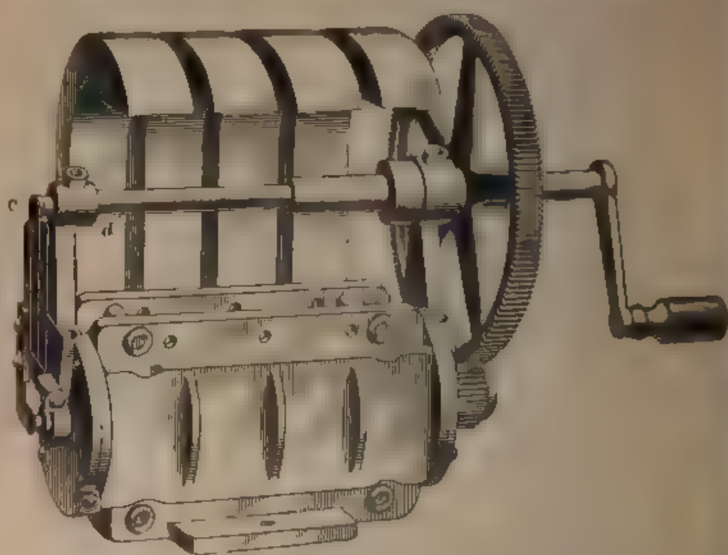


FIG. 13

which are made self-centering by turning shoulders in them to fit recesses turned in the ends of the armature core, which is made of soft, permeable, silicon iron. This construction gives a greater useful cross-section of soft iron and a larger and more regularly shaped winding space, as shown at (*a*), than does a continuous-shaft armature, as shown at (*b*). The two iron pole pieces *n*, *s*, which also form the frame, are held securely in position by heavy brass posts *o*, *p*, *q*, *r*; this gives a rigid construction regardless of the end plates

and allows the poles to be bored out in the position in which they are to remain. The end plates serve as bearings for the armature and crank-shafts. The shunt springs *c* are operated automatically by a longitudinal motion of the crank-

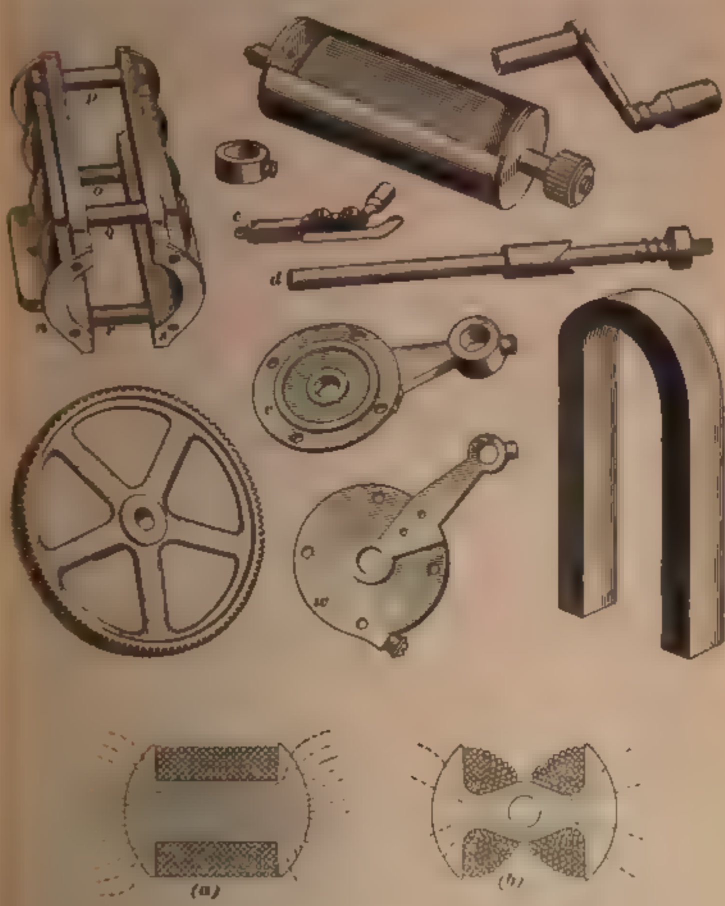


FIG. 14

shaft when it is turned. The four permanent magnets are ½ inch by ¾ inch special magnet steel. Each magnet is machine bent, tempered, copper-plated, and oxidized to prevent corrosion. It is claimed that this finish will

prevent rusting better than nickel plating. They are then magnetized.

MISCELLANEOUS TYPES OF AUTOMATIC SHUNTS

37. Western Electric Shunt.—Several forms of automatic shunt have already been described in connection with the various generators to which they belong. There are several others, however, that merit attention. One known as the Williams automatic shunt, and manufactured by the Western Electric Company, is used on nearly all the instruments of the American Bell Telephone Company. This is shown in Fig. 15, in which the large gear-wheel *G* is

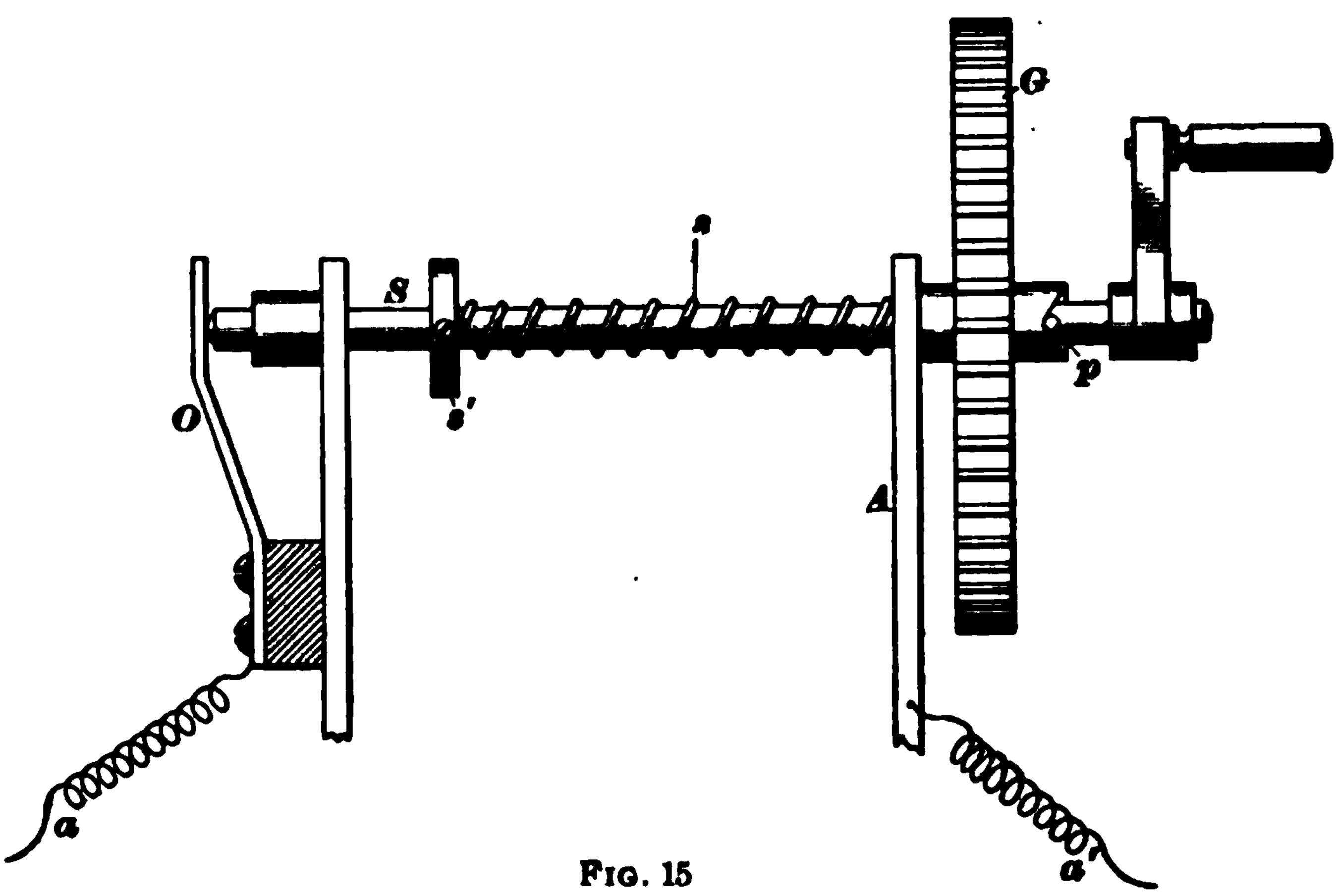


FIG. 15

loosely mounted on the crank-shaft *S*, and is free to turn thereon through a small portion of a revolution. The crank-shaft *S* is normally pressed toward the left by a spiral spring *s* bearing at one end against the end plate *A* of the generator, and at its other end against the collar *s'* rigidly secured to the crank-shaft.

The hub of the gear-wheel *G* is provided with a **V**-shaped notch in which rests a pin *p* secured directly to the crank-shaft *S*. A spring *O*, which is connected with one terminal *a* of the armature winding, rests against the end of the shaft *S* when at rest, and therefore completes a short circuit around

the armature, whose other terminal a' is connected directly with the frame of the generator, as usual. When the crank is turned, the pin p rides out of the notch in the hub of the gear-wheel, and in so doing pulls the shaft against the pressure of the spring s out of contact with the spring O, thus breaking the low-resistance path, or shunt, around the armature and leaving the latter effectively in the line.

38. Centrifugal Shunt.—In Fig. 16 is shown another form of automatic shunt, known as the Post, depending on the centrifugal action due to the rotation of the armature. A is the armature shaft, while w merely represents the armature coil. One end of this coil is fastened to the armature

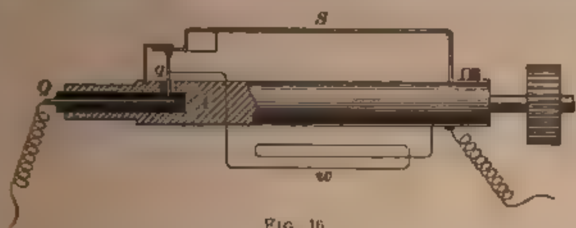


FIG. 16

shaft and the other end to the pin q connected with the pin Q in the ordinary manner. S is a spring secured at one end to the armature shaft and normally bearing at its other end on the pin q, so as to form a short circuit between that pin and the armature core. When, however, the armature is rotated, the weighted end of the spring S breaks circuit with the pin q, due to centrifugal force, and thus breaks the shunt while the generator is in action. This form of shunt, depending as it does on a single contact, which, owing to mechanical reasons, is necessarily light, has not proved altogether satisfactory in practice.

39. The Cook Shunt. In Fig. 17 is shown the Cook shunt, manufactured by the Sterling Electric Company. A sectional view of the crank-shaft and bearings, together with the shunt-operating mechanism, is shown at (a), while small detached views (b) and (c) illustate the respective positions of the contacts while the generator is in motion and at rest.

B, B are the bearings for the crank-shaft, these being supported by upwardly projecting arms from the end plates of the generator. The large gear-wheel G is mounted on a hub g'' that is rigidly secured to a sleeve g. The sleeve g turns within the bearings B, B, and is itself free to turn on the shaft s, but cannot slide sidewise in the bearings B, B. The connecting means between the shaft and the sleeve g is a spring S coiled around the sleeve, one end of which is fastened to a collar g' rigidly secured on the sleeve, while the other is fastened to a screw pin p passing through a diagonal slot in the sleeve and into the shaft. This pin is normally

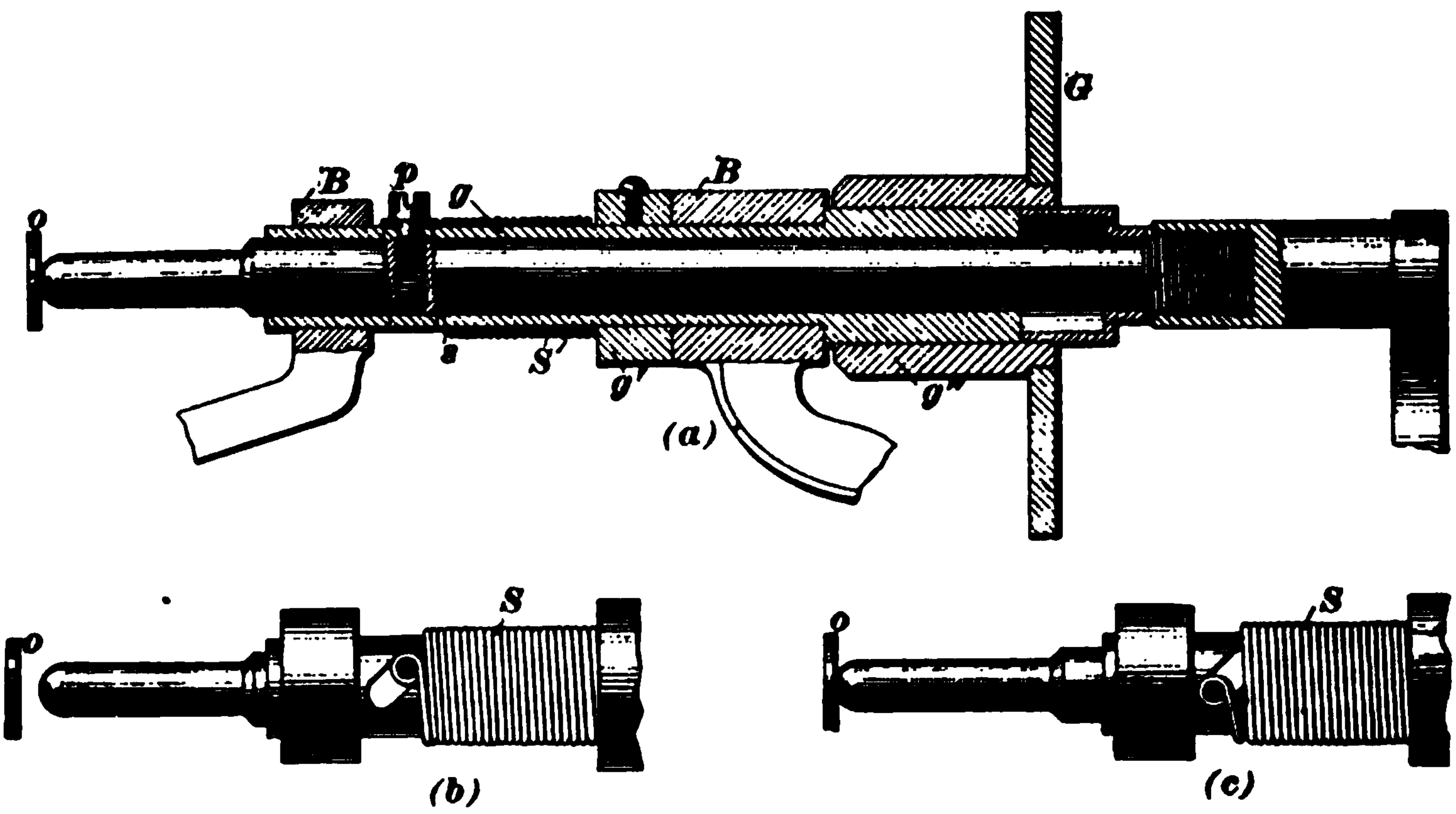


FIG. 17

held at one end of the slot by the tension of the spring, as shown at (*c*), and the shaft is thereby held in contact with the spring o, this contact completing the shunt around the armature. When, however, the crank is turned, the pin p rides against the sides of the slot against the tension of the spring S until it assumes the position shown at (*b*), thus breaking the connection between the shaft and the spring o and removing the shunt from the armature. Turning the crank right-handed moves pin p right-handed, thus tending to wind up the spring S, and since the collar g' cannot slide laterally, the pin with the shaft is moved to the right. It will be seen that the sleeve g and the large gear-wheel G

remain at rest until the pin p reaches the end of the slot, as shown at (b), after which the sleeve and gear-wheel turn with the shaft.

DIRECT-CURRENT MAGNETOS

40. It is sometimes desirable, in the operation of special systems of calling, to provide a generator that will send out impulses of current in the same direction, instead of in alternately opposite directions, as in the usual form. For bringing about this result, a commutator consisting of two segments a and b, Fig. 18, is mounted on the armature shaft. These two segments are insulated from each other and from the core of the armature, and to them are secured the two ends of the armature winding. At diametrically opposite sides of the commutator rest two brushes, as in the ordinary dynamo, these two brushes forming the terminals

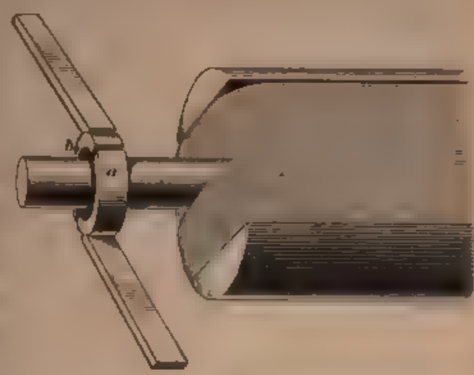


FIG. 18

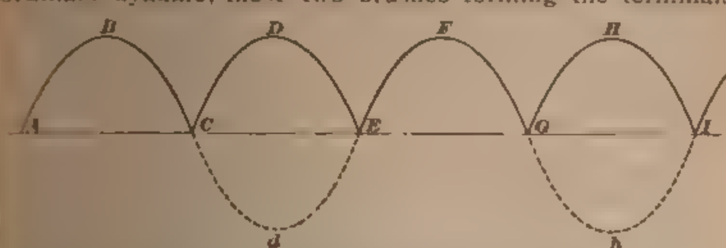


FIG. 19

of the generator. If these brushes are made to bear on the commutator at such points that when the brushes pass the dividing line between the two segments the current at that instant is just changing its direction, the impulses

sent out through the brushes will always be in the same direction; for just as the change in direction in the current is taking place within the armature winding, the connection through the brushes is reversed, and the two reversals taking place at the same time serve to keep the current in the same direction through the external circuit. The current is therefore of the form shown by the full line *A B C D E F G H I* in Fig. 19. It is direct but pulsating in character; it may be called a **rectified alternating current,** because the negative impulses are rectified in direction.

PULSATING-CURRENT GENERATORS

41. Where either one of two biased bells (the meaning of which will be explained later), connected to the same line

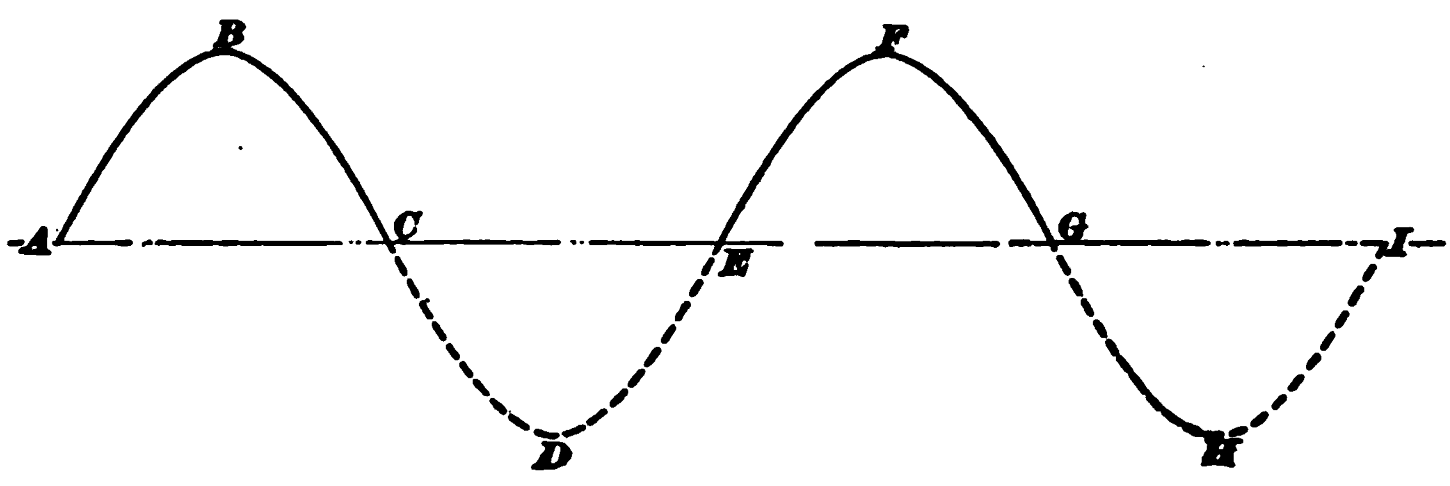


FIG. 20

circuit is to be rung, a so-called **pulsating-current generator** is used. In these generators either the positive or negative impulse is cut out altogether, so that the current curve approximates something like that shown by the full lines *A B C*, *E F G* in Fig. 20. The portion of the curve *A B C* is generated during one-half of a revolution of the armature. From *C* to *E*, during the next half revolution, the current in the external circuit, which is then open, is zero. Therefore, the part of the curve drawn in full lines represents the current actually flowing in the external circuit. The broken line *C D E* represents the course the curve would have taken had the circuit been closed all the time, in which case the current would have been alternating.

Evidently, if the circuit is connected to the generator armature only during each half revolution during which the impulses ABC and EFG are generated, there will be a pulsating current always in the same direction in the circuit, while if the circuit is connected to the armature only during the other half revolution, during which time the impulses CDE and GHI are generated, there will be a pulsating current in the opposite direction to that first considered. Hence, if ABC and EFG are positive (+) impulses, CDE and GHI are negative (−) impulses. Impulses in either direction in the external circuit will be separated by time intervals equal in length to a single impulse.

42. One arrangement for giving a pulsating current is shown in Fig. 21. The two brass segments d, f, constituting

FIG. 21

a collector ring, are insulated from each other by the insulation i and from the shaft and all other metal parts of the generator by the insulating ring e. One end of an ordinary shuttle-wound armature is connected to d and the other end to the segment f and also to the shaft or collecting ring h. The shaft, collecting ring, and armature, all revolve together. a, b, and c represent stationary brushes, a bearing on the ring or shaft h, and b, on d and f, and c, on d and f. During one-half of each revolution the electromotive force generated in the coil tends to send a current in the direction indicated by the arrows and consequently, as long as b rests on d, a current flows out of d through b into the line m-l-n and back from a into h. During the next half revolution, b rests on f; therefore, both a and b are connected to end w, while end v, being in contact with c, is open; hence, no

current is produced in the circuit. This arrangement, therefore, gives pulsating currents separated by intervals of equal length during which no current flows. Moreover, these impulses always flow in the direction *d-b-m-l-n-a-h*. Such a current in the side of the line *m-l* is called a **positive pulsating current** because it flows from the generator out over the line *m-l*. The current in the side of the line *l-n* is called a **negative pulsating current** because it flows from the line *l* back to the generator. To get a negative pulsating current in the side *m-l*, it is only necessary to reverse the connections between the line and the brushes, that is, connect *m* to *a* and *n* to *b*; this will also give a positive pulsating current in *n-l*.

To get a positive or negative pulsating current over either side of a line, the ground being used as a return, it is

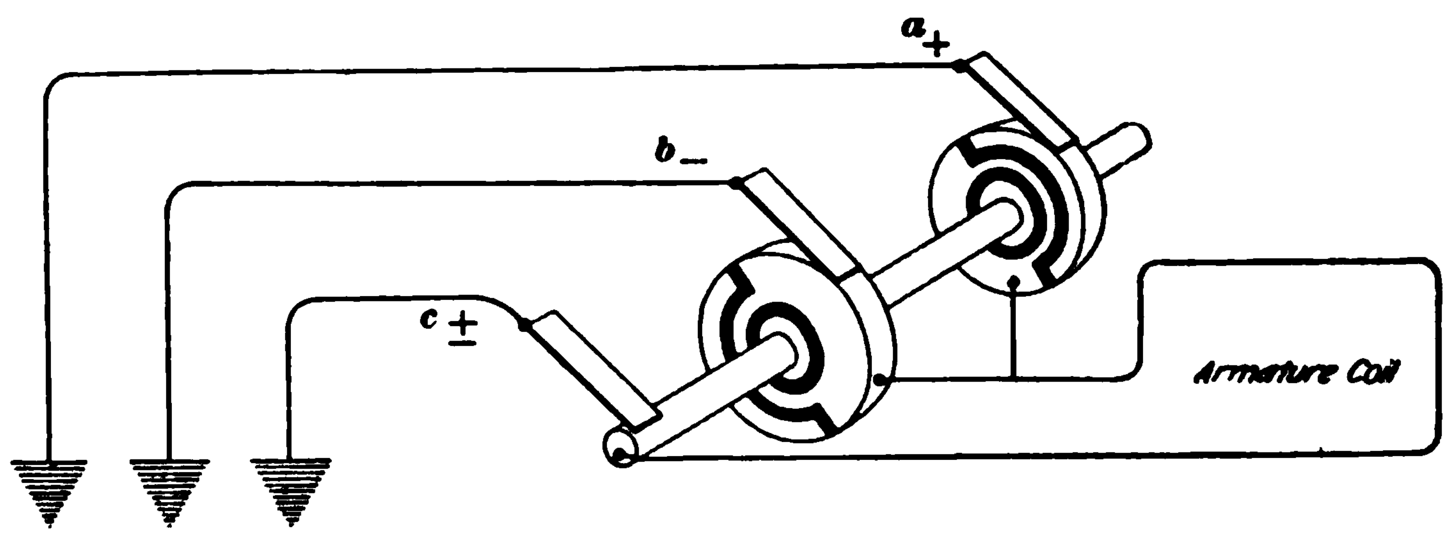


FIG. 22

simply necessary to connect the side of the line over which the current is desired, to the brush supplying the current in the direction desired, the other brush being temporarily grounded. Where it is desired to ground permanently one side of the generator, it is necessary to use two generators (or more complicated collecting rings and brushes), one brush on one machine and one brush of opposite polarity on the other machine being permanently grounded.

If the line circuit is connected across the brushes *b c*, a direct current will be obtained in the external circuit, as explained in connection with direct-current magnetos.

43. Positive or Negative Pulsating Currents. The arrangement shown in Fig. 22 may be used where one

generator must supply both positive and negative impulses and also where a permanent ground connection to the generator is required. The brush *c* forms the return circuit for either *a* or *b*. During one-half of each revolution, positive impulses may be obtained from *a*, and during the other half of each revolution, negative impulses may be obtained from *b*. Hence, current impulses can be obtained in either direction over any wire, the return circuit of which is formed by bells and the ground, by connecting that wire to *a* or *b*. A direct- or pulsating-current generator is frequently used in a bridging telephone instrument on toll lines, so that the exchange signal will be operated, but no bells on the same line will be rung. In this case, all calls go to a central point where an operator attends to the calls, in order to prevent free messages even over the same line. The central operator does all the calling and can, therefore, check all messages. The system also gives the signaling into the hands of a competent person, and there are not so many misunderstandings.

Fig. 23

44. Arrangements of Springs to Obtain Alternating, Direct, or Pulsating Currents.—Fig. 23 shows an arrangement of springs and two-part commutator of a hand generator made by the Stromberg-Carlson Telephone Manufacturing Company, whereby alternating, direct, negative-pulsating, or positive-pulsating current may be obtained. The springs are all made of German silver, provided with platinum contacts and substantial terminal screws so that connections can be readily made to them. *1* is always connected to one end of the armature winding and *1* to the other end, thus giving alternating current in any circuit connected to these terminals. *2* connects to one stationary brush and *3* to a diametrically opposite stationary brush between which a

two-part commutator revolves, each segment of which is permanently connected to one end of the armature winding; any circuit connected to these two terminals receives, therefore, the rectified alternating current, that is, direct current, which is slightly pulsating in character, but sufficiently steady for the purpose intended. Since *2* connects to one stationary brush and *4* always to the same end of the armature winding, a pulsating current always in the same direction, the intermediate impulses in the opposite direction being omitted, is obtained by using terminals *2* and *4*. Connecting a circuit to *2* and *4* gives a negative impulse in the wire connected to *2*. *3* connects to the other stationary brush; hence, connecting a circuit to *3* and *4* gives a positive-pulsating current in the wire connected to *3*, the negative impulses being omitted.

POLARIZED BELLS

DETAILS OF POLARIZED BELL CONSTRUCTION

45. Electromagnets.—The cores of the electromagnets in polarized bells should be of the best quality of soft iron obtainable. An imported iron from Sweden or Norway is used for these parts in the bells of the best manufacture. A good way of testing the quality of a piece of iron for a ringer core is to stroke it across the poles of a powerful electromagnet in exactly the same manner as if it were a bar of steel that it was desired to magnetize. If the iron is of suitable quality for the purpose, it will retain practically no magnetism, and a good test of this is to dip one of its ends into iron filings. If the core is of ordinary iron, a large number of filings will adhere to it, while if it is of the best grade of Norway or Swedish iron, properly annealed, very few, or none, of the filings will cling to it. In no place in a telephone instrument does the quality of iron play a more important part than in the ringer-magnet cores; for they are placed in a weak field of force, due to the proximity of a permanent magnet, and the strength of this field

must be rapidly altered by the alternating currents from a distant generator. If the cores are hard, a current in one direction will set up magnetism in them, which it will be difficult for a succeeding current in the opposite direction to overcome; and inasmuch as impulses alternately opposite in direction follow each other at a high rate of speed, each impulse will find difficulty in overcoming the effects of the one before it.

46. Frame. The frame of the ringer on which the electromagnets of the armature is mounted assumes widely different forms in different styles of instruments, and frequently includes the permanent magnet and the yoke piece. The yoke piece completing the magnetic circuit between the rear ends of the two cores should be of the same quality of iron as the cores themselves. In some ringers, this yoke assumes the form of a heavy cast-iron U-shaped bar, which supports the two coils at opposite ends. This is very detrimental to the efficient action of the ringer, as the yoke frequently becomes polarized in one direction or the other, thus causing the armature to stick to such an extent that it cannot be freed by the feeble impulses of current coming in over a long line from the generator at another station.

The same remarks apply to the armature of the bell that carries the striker or hammer; even the base should not be made of cast iron. In general, it may be said that, in order to obtain the greatest sensitiveness, all portions of the structure of the ringer that form a part of the magnetic circuit should be of the finest grade of soft iron procurable, with the exception of the permanent magnet, which, of course, should be made of hardened steel.

Some makers use ordinary cold-rolled soft steel for their ringers, and while the parts are annealed carefully, they are not as good as the ringers in which Norway or Swedish iron is used for the cores, base, and armature. Any screws included in this magnetic circuit should also be annealed. The reason the soft steel is used is partly because of its

cheaper cost, but mostly because the machine work is much more easy than with Norway or Swedish iron.

The gongs should be made of brass or bell metal, not of iron or steel, and they should be heavily plated with nickel.

47. Permanent Magnet.—The stronger the permanent magnet, up to a certain limit, the more sensitive will the ringer be. The steel for the permanent magnet should be of the same quality and be treated and magnetized in the same manner as the steel used for the permanent magnets of receivers and generators. In designing bells, care should be taken that the permanent magnet is not included directly in the magnetic circuit of a coil, the current through which is reversed in direction, because in such cases the permanent magnet is very apt to become demagnetized or weakened to such an extent as to impair the efficiency of the apparatus; for if the lines of force produced by the coil pass through the magnet first in one direction and then in the other, the magnet will be alternately weakened and strengthened. The result of this alternate strengthening and weakening of the permanent magnet will be to gradually demagnetize it, because the strengthening effect produced by one impulse will not be as great as the weakening effect produced by the next impulse. A bell in which a permanent magnet is included in the magnetic circuit of the coil, should be avoided, although it may last a long time if very heavy currents are not passed through it.

48. The heads, forming with the cores the spools on which the coils are wound, are usually of fiber pressed into position on the cores and secured thereto by friction only. Before winding, the core is carefully insulated by a layer of oiled paper. The wire used for winding the coils is usually single-silk insulated and of a size suitable for the conditions under which the bell is to be used. The ordinary polarized bell magnets for use with the common form of series-telephone is wound with No. 31 B. & S. gauge copper wire, each spool having a resistance of from 50 to 60 ohms, thus giving the two spools, when placed in series, a joint resistance of

from 100 to 120 ohms. This figure is varied between wide limits to meet different conditions. A better series-bell may usually be obtained by winding the spools with No. 30 B. & S. wire to a resistance of 60 to 80 ohms. The 80-ohm bell used by the Bell companies contains 4,200 turns of the No. 30 B. & S. single silk-covered wire. It should be possible to ring an 80-ohm bell with .08 ampere, a 1,000-ohm bell by .02 ampere, and a 1,600-ohm bell having 20,000 turns by .015 ampere.

49. Series and bridging bells are of the same general construction. Series-bells are used where one or more bells are connected in series in the same circuit; therefore the whole current passes through each bell. Bridging bells are used where one or more bells are connected across the same circuit. Where there are several in parallel across the same circuit, the total current subdivides, about an equal amount flowing through each bell. In this case, the current through each bell is smaller than that through a series-bell; hence, more turns are required on a bridging bell, in order to have the same number of ampere-turns as on a series-bell. Hence, the coil must be made larger. The coils are usually made considerably longer, and hence bridging bells are longer than series-bells.

50. Biased Bells.—Bells adapted to be rung by pulsating currents in one direction only, are called **biased bells.** They are extensively used in party-line telephone systems. It has been explained that current impulses first in one direction and then in the opposite direction will cause first one end of the armature to be drawn toward its core and then the opposite end of the armature toward the other core, thus ringing the bell. If, now, the current impulses that cause the armature to be drawn against one core are omitted, but a spring is used to force the armature toward this core, impulses in the opposite direction will pull the armature against the other core in spite of the spring, but between each impulse the armature will be promptly drawn back by the spring to its normal position against one core.

Thus, a series of impulses in the proper direction separated by equal intervals of no current will cause the hammer to hit one gong and the spring will cause the hammer to hit the other gong alternately. The interval of no current between two impulses should be of the same length as a current impulse.

A pulsating current of the character represented by the full lines *ABC* and *EFG* only in Fig. 20 is suitable for this purpose. The only effect of a current impulse in the opposite direction will be to hold the armature more tightly in the normal position. Hence, the alternating current ordinarily used for ringing polarized bells will also ring biased bells, no matter in which direction the armature is biased by the spring. However, if two oppositely biased bells are connected in parallel, a pulsating current in one direction through both bells, will only ring one of the two bells, while a pulsating current in the opposite direction will ring only the other bell, but an alternating current will ring both bells. Hence, the use of biased bells and pulsating currents enables either one of two bells in the same circuit to be rung; this is called **selective ringing.**

ADJUSTMENT OF BELLS

51. Adjustment.—A ringer should be adjustable in several respects, the principal one of which, however, is the adjustment between the relative positions of the bell hammer and the gongs between which it plays. The best way of accomplishing this is by providing for a lateral movement of the supports on which the gongs are mounted. Another adjustment which a ringer frequently needs is in the distance between the armature and the cores. This is accomplished in a number of ways, as shown in connection with the various bells. In order to get the most sensitive results, the armature should be as close as possible without sacrificing the length of a stroke. If the length of the stroke is too short, the gongs will not receive a sufficiently hard blow. The armature of a bell should have a play of from .015 to .017 inch, or about $\frac{1}{64}$ inch.

In adjusting the armature of a ringer, it should be placed so that, when the clapper is in the middle of the stroke, both ends of the armature are equidistant from the poles of the electromagnet, and at such a distance from the poles that, when the armature is in either extreme position, the clapper does not quite touch the gongs. When the bell is rung, the elasticity of the hammer rod will allow the gong to be struck, making a clear and loud tone. When the clapper touches the gong at one or both ends of the stroke, it is likely to muffle the bell by interfering with the vibration of the gongs. When the line is long, the armature may be set closer to the magnet, and also the gongs a little closer together. A bell whose armature sticks to either pole is not well constructed. The armature must be arranged so that it cannot touch the iron part of either core.

In order to so adjust a biased bell that it will be rung by a current in one direction and not in the other, the armature should be so placed that, with the biasing spring properly attached, one end of the armature should be drawn against the brass pin inserted in the magnet pole. The spring should have sufficient tension to permit the hammer to be thrown by it in one direction, with the same force as the current throws it in the other direction. The pivot of the armature should be adjusted so as to have no looseness, or it will rattle.

COMMERCIAL TYPES OF POLARIZED BELLS

52. American Bell Ringer.—One form of polarized bell used by the Bell companies is shown in Fig. 24, in which *m*, *m* represent the electromagnets wound on the soft-iron cores *c*, *l*, secured at their upper ends to the yoke piece *y*. Brass rods *g*, *g*, riveted into the yoke piece *y*, support at their lower ends a bracket *b* having two projecting ears, in which the armature *a* is pivoted by means of pivot screws *s*, *s*. Carried by this armature is the hammer *h*, consisting of a slender brass rod and a ball for striking the gongs. Carried on the yoke piece *y* is the permanent magnet *N S*, bent as shown. This magnet serves to give the

yoke *y*, and consequently the core ends, or pole pieces, *e*, *f* a positive, or north, polarity, and the two ends of the armature *a* opposite the poles *e*, *f* negative, or south, polarity. Each end of the armature will therefore be attracted with about equal force by the two poles *e*, *f*, and the armature will adhere to the one to which it happens to be the nearer.

The coils are wound in opposite directions, so that a current traversing them in series will tend to make one of the poles positive and the other negative, or vice versa, according to its direction. The action of this bell should be clear from the explanation previously given.

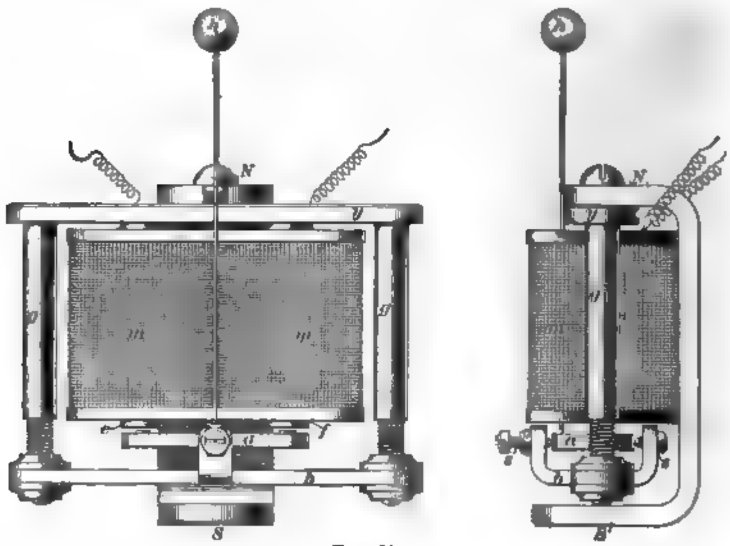


FIG. 24

The bell shown in this figure is the size used in series telephones. Bridging bells are longer in order to accommodate longer coils of higher resistance and more turns. The 1,000-ohm bridging bell used by the Bell companies has the following dimensions: Distance between centers of rods *g g* (see Fig. 24), 2½ inches; distance *O* (see Fig. 25), between centers of cores, 1¼ inches; diameter of cores *X*, ⅜ inch; length of cores *T*, 2½ inches; length of winding space on coil *Z*, 2⅛ inches; thickness *F* of fiber heads of

spools, $\frac{1}{2}$ inch; outside diameter of spool D, $\frac{15}{16}$ inch; permanent magnet, width Q, $\frac{3}{4}$ inch; thickness E, $\frac{3}{16}$ inch; length when bent V, $3\frac{3}{4}$ inches; length of armature A, $1\frac{3}{4}$ inches. The Ericsson 1,600-ohm bell has the following dimensions: O, $1\frac{1}{16}$ inches; X, $\frac{3}{8}$ inch; T, $2\frac{1}{2}$ inches; Z, 2 inches; D, 1 inch; Q, $\frac{5}{8}$ inch; E, $\frac{3}{16}$ inch; W, $1\frac{5}{16}$ inches; V, $3\frac{3}{8}$ inches; A, $1\frac{13}{16}$ inches; thickness of armature P, $\frac{7}{32}$ inch; the length of tapper rod, about $4\frac{1}{2}$ inches.

53. Kellogg Ringer.—The bell manufactured by the Kellogg Switchboard and Supply Company is shown in

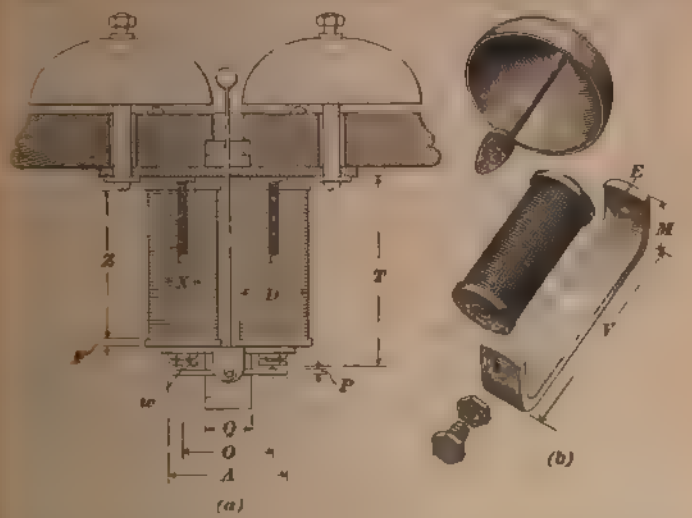


FIG. 25

Fig. 25 (*a*), and some parts in (*b*). In this bell, the gongs are mounted on rigid metal posts that, in turn, are adjustably fastened by machine screws to the same frame as the ringer magnets, and, hence, the adjustment is independent of the woodwork of the telephone case. The bell is adjusted by varying the distance between the pole pieces and the armature by means of screws in the pole pieces, which are readily moved toward or from the armature by an ordinary wrench and afterwards locked in place by a locknut. It is, therefore, unnecessary to bend the tapper, or rod, or change the

adjustment of the gongs in order to regulate the stroke of the tapper. This is said to afford a very delicate adjustment that remains permanent after once being set. A further advantage claimed by this method of adjustment is that it allows the ringer to be so designed that the tapper will always strike the gongs at their most responsive part, regardless of the adjustment of the armature. All the coils used in these ringers, whether for series or bridging instruments, are made of the long type and are interchangeable. This allows the use of a larger size wire for the lower resistance or series windings. A rivet *w* of non-magnetic material prevents contact between the iron cores and the armature. All the exposed iron and steel parts are copper plated and oxidized, which it is claimed affords much better protection from corrosion than nickel plating. The gongs and other parts of the ringer, that show on the outside of the telephone box, however, are nickel plated and polished. Ringers kept in stock are wound to 80, 500, 1,000, 1,600, 2,500, and 2,600 ohms.

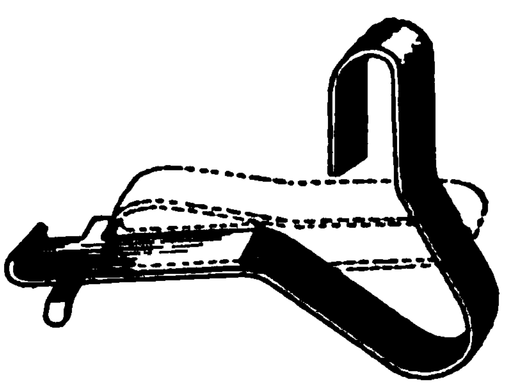


FIG. 26

54. The Kellogg leaf biasing spring for use with the same make of bell is shown in Fig. 26. It is designed to slip over the free end of the permanent magnet and to hold the armature against one pole piece. It is also used in their two-party selective system to prevent the discharge of a condenser used in the bell circuit from causing the ringer to give a single tap.

55. The **Dean Electric Company's ringer** is shown in Fig. 27 (*a*), and the various parts at (*b*). The maximum pull of the cores on the armature is secured by making the air gap as small as possible. This is accomplished by the use of a non-magnetic metal ring separator, shown at *v*, Fig. 28 (*a*), instead of the usual rivet-head separator shown at *w*, Fig. 28 (*b*). When the rivet *w* becomes worn or the armature is not properly adjusted, the armature may touch the core, thereby causing it to stick or ring on one

gong only. The ring separator v is the neck of the brass spool head c and is swaged to the core o so as to project about $\frac{3}{1000}$ inch beyond the same. This forms a complete

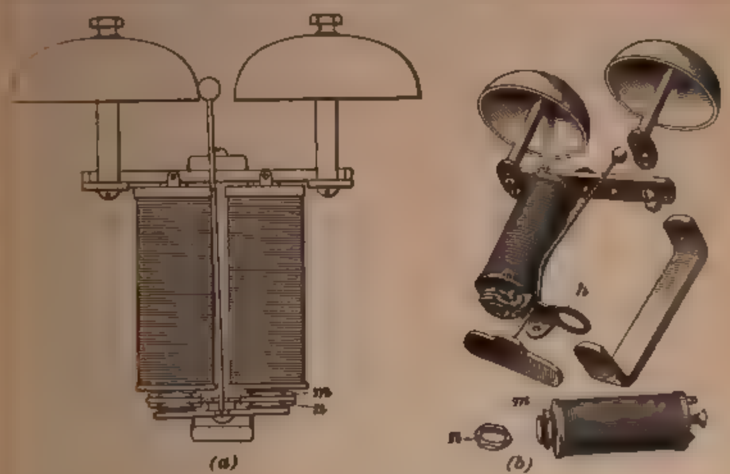


FIG. 27

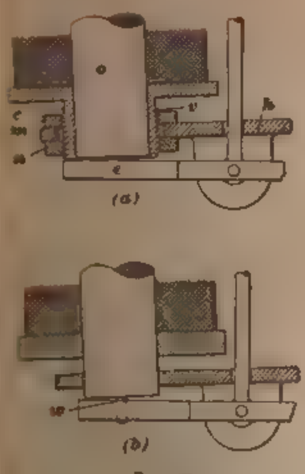


FIG. 28

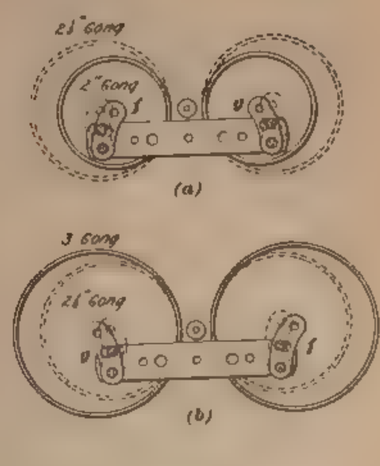


FIG. 29

ring on which the armature e strikes in its movement, and regardless of poor adjustment of the ringer or length of the stroke, it can never touch the iron of the core and stick. A

very close working distance can thus be utilized without danger of this trouble.

This ringer is adjusted by varying the position of the armature support *h* and locking it in place by means of the hexagonal nuts *m*, *n* threaded over the spool necks.

Ringers that do not depend on the outside mounting for the support of the gong posts, are usually limited to one size of gongs. This limitation is very ingeniously avoided in this ringer by shaping the gong-post adjustments as shown at *f* and *g*, Fig. 29. With the posts assembled as illustrated in view (*a*), gongs from 2 inches to 2½ inches in diameter are accommodated, while with the posts reversed to opposite ends of the ringer frame, as shown in view (*b*), gongs from 2½ inches to 3 inches in diameter can be accommodated. With the gong post in either of these positions, 2½-inch gongs, which are standard for all regular size telephones, can be used and adjusted for any practical length of tapper stroke.

FIG. 30

56. Stromberg-Carlson Ringer.—In Fig. 30 is shown the standard bridging ringer made by the Stromberg-Carlson Telephone Manufacturing Company. The brass plate *f* is forced over the cores and binds the spools in place, and the plate *d* is made of spring brass of sufficient thickness to allow as much adjustment of the armature as may ever be necessary. The adjustment of the ringer is effected by turning the screw *b*, which has a shoulder resting against plate *d*, while the lower end is threaded into the binding plate *f*. Turning the screw *b* to the right causes plate *d* to

be drawn downwards, thus bringing the armature *c* nearer the cores and decreasing the movement of the striker. Turning the screw to the left increases the distance between the armature and cores and increases the movement of the striker. It may be fitted with an adjustable spiral spring *s* for converting it into a biased ringer.

57. Three-Pole Ringer.—A ringer at one time extensively advertised is shown in Fig. 31, in which *O* is a permanent magnet, so magnetized as to have one of its poles at its center *N*, the two ends forming poles of like polarity. Thus, if the center of the permanent magnet *N* is of north polarity, the two terminals *S*, *S* will be of south polarity. The coil consists of a single spool having a soft-iron bar for a core, riveted to two heads *P*, *P′* of very soft sheet iron. These two heads are secured to the inner faces of the ends of the permanent magnet by means of properly bent lugs *p*, *p* and screws *o*, *o*. The armature *Q* is pivoted at its center within a yoke piece *R* adjustably mounted in a bushing *T* secured to the center of the permanent magnet. The distance between the ends of the armature and the pole pieces *P*, *P′* may be adjusted by sliding the rod supporting the yoke piece within the bushing, it being clamped in place by the setscrew *t*.

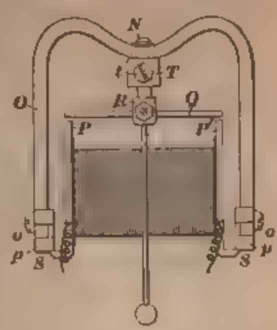


FIG. 31

The magnetic lines pass the center point *N* of the U-shaped magnet to the center of the armature, where they divide, half passing one way through the armature to the pole piece *P′* and half passing in the opposite direction to the pole piece *P*; thence they continue through each pole piece to the extremities *S*, *S* of the permanent magnet, and back to the center point. It will be seen that the core of the coil forms no part of this circuit, because both its ends are of the same polarity. When the single coil is traversed by a current in one direction, the core is magnetized, and the

return path of its magnetic circuit is through the soft-iron armature Q. Under normal conditions, the ends of the armature Q are attracted with equal force by the pole pieces, and the armature will therefore stick to either one or the other, according to which it happens to be nearest. If the current through the coil is of such direction as to tend to impart a north polarity to the pole P' and a south polarity to the pole P, the pole P' will be weakened and the pole P strengthened, so that the armature will be attracted by the latter. By reversing the current, the armature is drawn in the opposite direction.

The advantage claimed for this ringer was the fact that no lines of force pass normally through the core, which is therefore in a condition to be most readily affected by the magnetizing force of the coil. This bell was made by the Williams Electric Company. The Williams-Abbott Co. made a somewhat similar bell. In the Williams and Williams-Abbott ringers, the permanent magnet was quite long and of sufficiently high reluctance so that very few, if any, of the lines of force produced by the current in the coil pass through it. The greatest drawback to this style of ringer is probably due to the fact that it is difficult to get a high-wound coil without making the ringer too large, or using too thin wire for winding the coil. The former is not desirable on account of the size, while if a very fine wire is used, the ringer is too easily burnt out. This type of ringer is no longer made and is rapidly going out of use, probably because it has not proved as efficient and durable under practical conditions as the ordinary standard type of ringer.

CIRCUITS OF TELEPHONE INSTRUMENTS

LOCAL-BATTERY TELEPHONES

1. Telephone Instruments may be divided into three general classes, as follows: The first class, called **local-battery telephones,** includes all telephones having primary batteries in or near them for supplying current to the transmitters, and magneto-generators for signaling purposes. The second class, called **local-battery talking** and **common-battery signaling telephones** and used on common-battery supervisory systems, have a local battery for supplying current to the transmitter, but the central office, to which the telephone lines connect it, supplies current from a common battery, there located, for signaling purposes; no magneto-generator is required. The third class, called **common-battery,** or **central-energy, telephones,** requires no local battery or magneto-generator; all current, for both talking and signaling purposes, is supplied from one common battery located at the central office, to which the line wires connect the telephone. There are some instruments that are not included in the above classes, but they cannot be classified very well.

The connections of local-battery instruments, which include series and bridging telephones of both the wall and desk patterns, will be presently considered. The other two classes of instruments usually have an ordinary polarized bell varying in resistance from about 80 to 5,000 ohms (sometimes in series with a condenser of about 2 microfarads capacity) connected across the line circuit, or between one

line wire and the ground, when the receiver rests on the hook switch. No generators are required, as the central office is signaled by the mere removal of the receiver from the hook. The transmitters and receivers are arranged in about the same manner in local-battery talking and common-battery signaling telephones as in ordinary local-battery telephones; but in central-energy telephones, they are arranged in various ways. The circuits of central-energy and local-battery talking and common-battery signaling telephones depend somewhat on the exchange system with which they are used and can, therefore, be shown better in connection with switchboard diagrams.

2. Functions of Hook Switches.—The apparatus for sending and receiving articulate speech and signals perform entirely separate functions, and although they are never in use at the same time, both are absolutely essential to the successful working of an instrument. In order that a separate circuit need not be provided for the calling and the signaling apparatus, arrangements are made by which the two sets of apparatus may be alternately switched into and out of the line circuit. It is necessary that the call-receiving device—the ringer—shall be left in the circuit during the idle periods of the instrument, in order that an incoming call may be sounded. As soon, however, as a call is received or sent, there is no more need of the calling apparatus, and the telephone apparatus proper is then brought into the circuit. The two are never left in the circuit at the same time, because it would then be necessary, in signaling, for the generator currents to pass through the talking apparatus; and, in talking, for the telephone, or *voice currents*, to pass through the signaling apparatus. This alternative switching of the talking and signaling apparatus into the circuit was at first accomplished by ordinary hand switches, but it was soon discovered that people could not be relied on to operate them intelligently; as a remedy to what seemed at first a most serious trouble, a device was designed to accomplish these changes of circuit automatically, without the volition of the

user of the telephone. Such devices are termed *hook switches* and are usually operated by the weight of the receiver.

The **hook switch** usually consists of a lever pivoted at one end and provided with a hook or fork forming a convenient support for the receiver. The lever is normally pressed upwards by a spring, the strength of which, however, is not sufficient to hold the lever in its raised position when subjected to the weight of the receiver. By the up-and-down motions of the lever, certain contacts are made or broken, which bring about the desired changes in the circuits.

CIRCUITS OF LOCAL-BATTERY TELEPHONES

POST TELEPHONE CIRCUIT

3. A primary knowledge of the operation and functions of the hook switch may be best understood by considering the circuits of a telephone instrument. The **Post method** of connecting the various devices used in a series-telephone

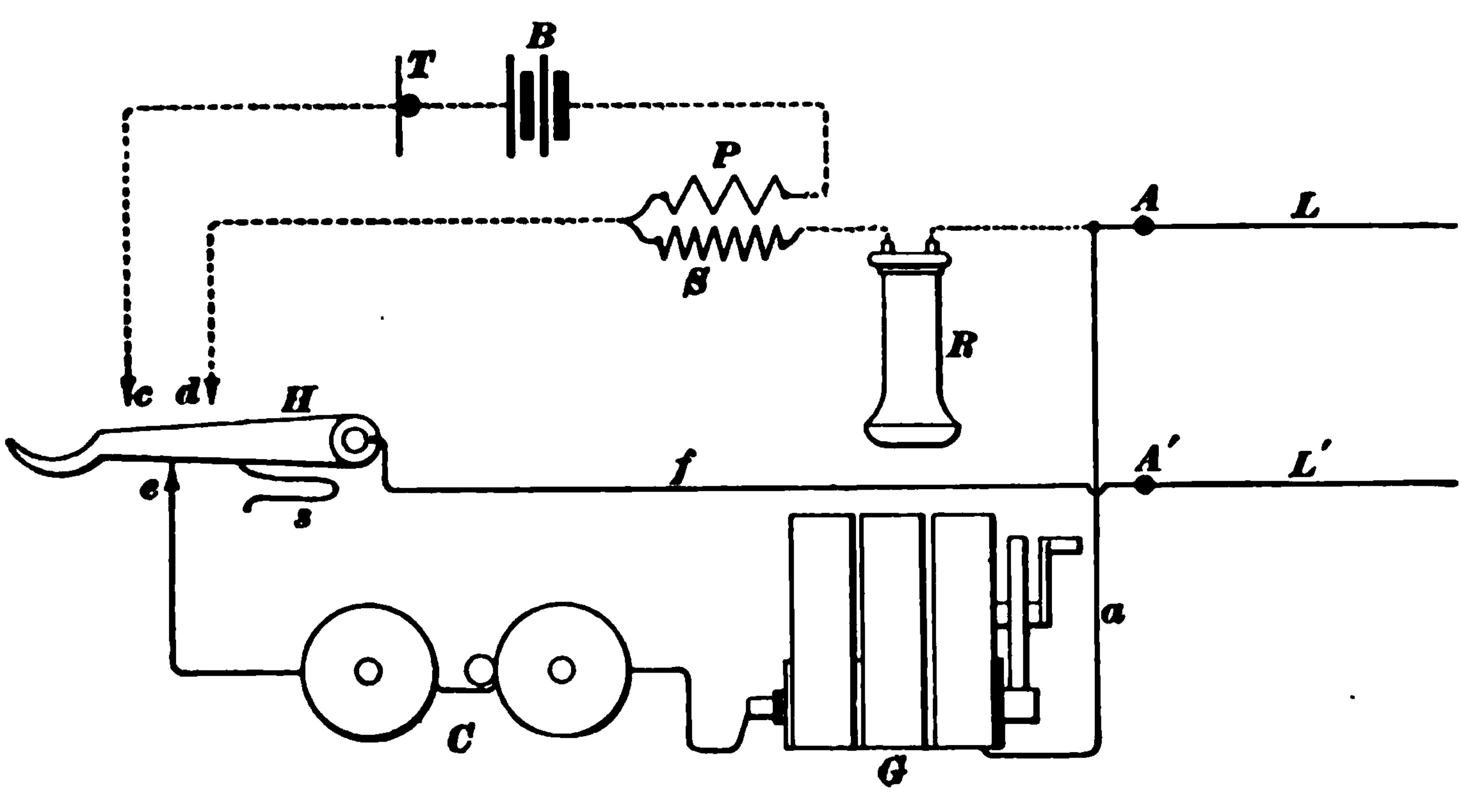


Fig. 1

of the local-battery class is shown in a simplified form, for convenience of illustration, in Figs. 1 and 2, the former representing the circuits as they exist when the receiver is on the hook, and the latter, the circuits when the receiver is

removed from the hook. The circuits that are in operation in each case are represented by full lines, and those that are idle, by dotted lines. In Figs. 1 and 2, *A*, *A'* represent the binding posts of the telephone instrument as a whole, in which the line wires *L*, *L'* terminate. *H* is the hook-switch lever pressed upwards by the small spring *s* against the two contacts *c*, *d*. When, however, it is subjected to the weight of the receiver, as shown in Fig. 1, the lever is depressed against the tension of the spring *s* in such a manner as to open the contacts *c*, *d* and make a contact with *e*.

4. Hook Lever Down.—When the hook is in the position shown in Fig. 1, the circuit may be traced from the line

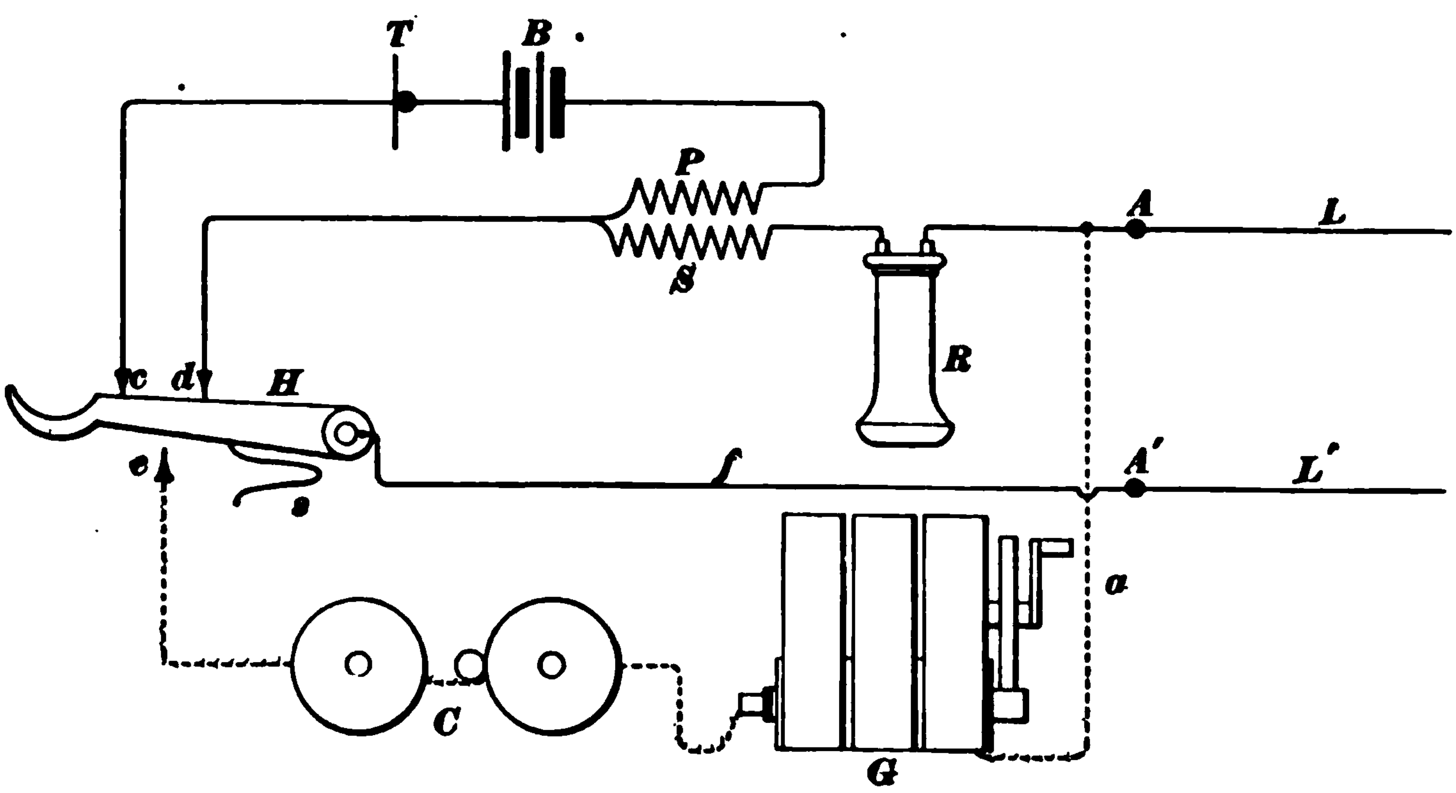


FIG. 2

wire *L* and the binding post *A* through the wire *a* to the generator *G*, thence through the bell *C* to the contact point *e* of the hook switch. As this point is in metallic contact with the lever *H*, the circuit is rendered complete through the wire *f* to the binding post *A'* and to the line wire *L'*, or to the ground, in case a ground return is used. In this position, the circuits containing the talking apparatus, consisting of the transmitter *T*, the battery *B*, the receiver *R*, and the primary and secondary coils *P*, *S*, are all open at the contacts *c*, *d*.

5. Hook Lever Up.—When the receiver is removed from the hook, the lever rises and breaks contact with the

point *e*, thus rendering the branch of the circuit containing the generator *G* and the polarized bell *C* inoperative. By making contact, however, with the points *c* and *d*, two new circuits are closed, one of which may be traced from the line wire *L* through the receiver *R* and the secondary coil *S* of the induction coil to the point *d* of the hook, and thence by means of the hook lever and the wire *f* to the line wire *L'* or ground, as the case may be. Thus, the circuit for incoming voice currents from a distant station, or for outgoing voice currents originating in the secondary coil *S* by induction from the primary circuit *P*, is made complete. Another circuit containing the transmitter *T*, the battery *B*, and the primary *P* is closed by virtue of the hook lever making contact with both the points *c* and *d*. This is the local circuit of the telephone instrument in which the transmitter acts, as already described.

The circuit closed when the switch is down is known as the *calling*, or *signaling, circuit;* the circuit containing the receiver and the secondary winding of the induction coil, and closed when the switch is up, as the *secondary talking circuit*, or simply the *secondary circuit;* and the circuit containing the transmitter, battery, and the primary of the induction coil, as the *local transmitter*, or *primary talking circuit*, or simply the *primary circuit.*

WESTERN ELECTRIC NO. 2 TELEPHONE CIRCUIT

6. The method of connecting the magneto-bell and telephone shown in Fig. 3 is known as the **Western Electric No. 2 diagram**; it has been used quite extensively by the Bell Telephone Company. The circuits can be readily traced by the reader. It will be noticed that the signaling circuit and the secondary talking circuit are always connected to the line wires; neither are ever on open circuit, but each is short-circuited when it is not in use by the wires *m* and *n*, respectively. That is, when the switch *H* is down, the receiver and secondary coil are short-circuited by the wire *n*, the primary circuit being on open circuit; when the switch is

up, the generator and bell are short-circuited by the wire *m* and the primary circuit is closed at *c*.

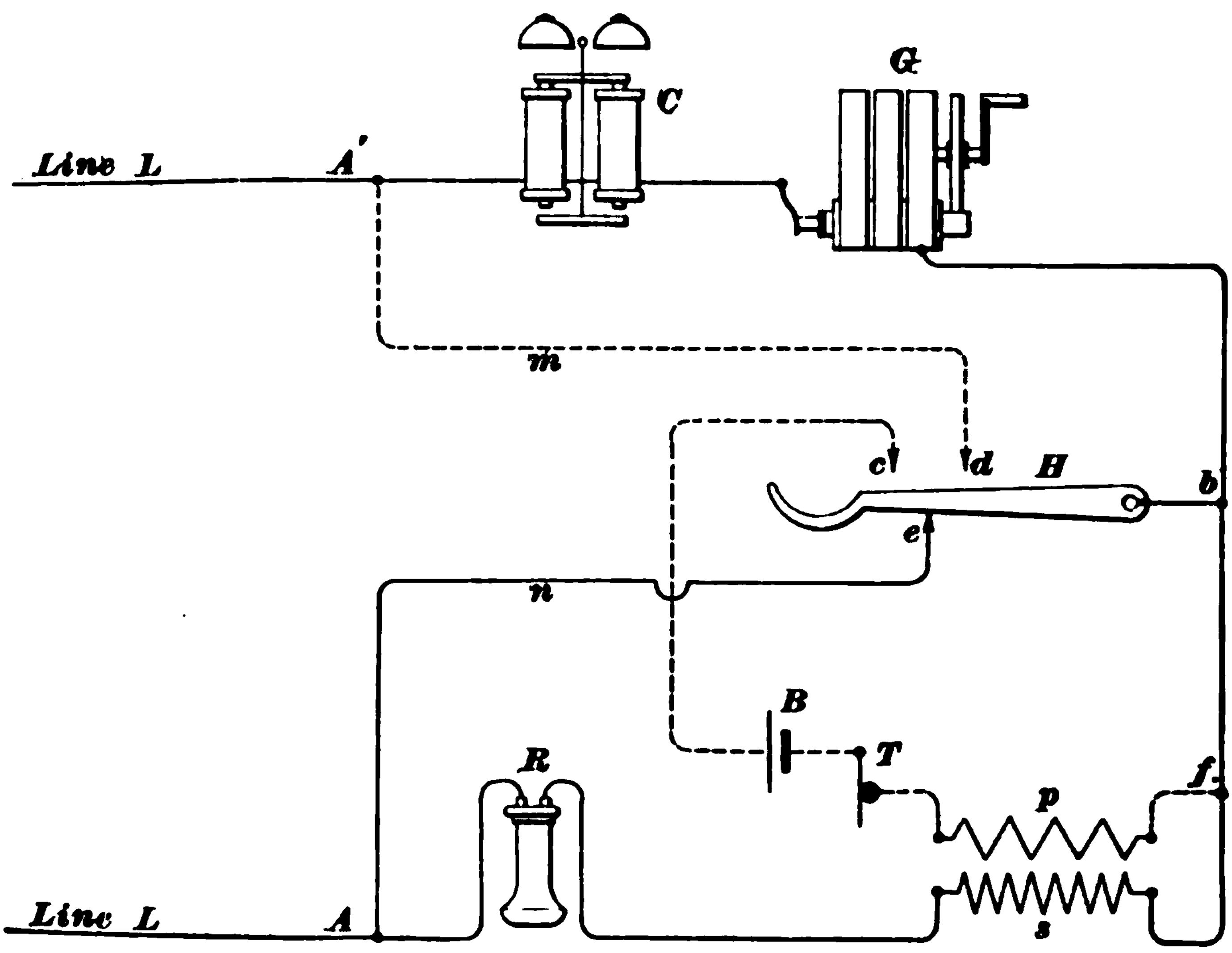


FIG. 8

HOOK SWITCHES

7. The **Warner hook switch**, shown in Fig. 4, has been used extensively by the American Bell Telephone Company. The lever *l* carrying the hook forming the receiver support on its outer end is pivoted to a bracket screwed to the inside of the magneto-box. The lever is held in the position shown, when released from the weight of the receiver, by the action of the spring *e* pressing against the rubber knob *f*. In this position, a knife edge formed on the short arm *a* of the lever makes contact with the springs *c*, *d*, which press outwardly from the side of the box, thus not only putting them in metallic contact with the lever, but electrically connecting them with each other. When the hook is depressed, the metallic pin *h* on the under side of the lever makes contact with the spring *e*, thus making electrical contact between the lever and that spring. At the same time, the knife edge on the arm *a* of the lever is

withdrawn from contact with the springs c and d, which now rest against the hard-rubber block b carried on the under side of the short arm of the lever, as shown. The spring g always presses against the rounded portion of the lever, so as to insure a perfect contact between it and the bracket, it having been found that the contact through the pivot screw could not be relied on for transmitting the feeble voice currents. All contact points on this hook are faced with platinum, in order that they may be bright and clean and not subject to corrosion, either from atmospheric influence or from sparking, which often takes place when the current is broken. A slight rubbing action also takes place between all the surfaces when the circuits are made or broken, which further tends toward preserving clean, bright contacts. This hook switch, although very simple, represents a development attained only after several years of actual experience.

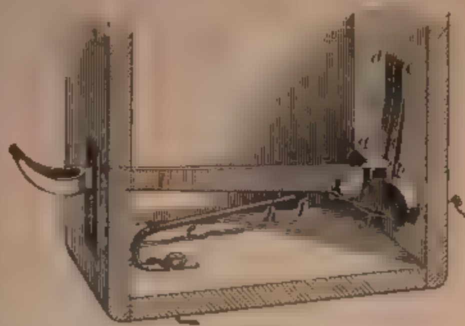


FIG. 4

8. Prevention of Poor Contacts.—One of the chief sources of trouble in a telephone is the hook switch, when it is not properly designed and constructed. The slightest particle of dust, entirely invisible to the eye, lodging between the contact surfaces on the springs and on the lever, will frequently cause an open circuit or a point of such high resistance that it amounts to the same thing. Again, a loose contact between the two springs, especially if it be in circuit with the transmitter battery, may cause intermittent and exceedingly disagreeable noises in the receiver, which may entirely prevent the transmission of speech. As a rule, the signaling contacts, that is, those closed by the switch to complete the signaling circuit when the telephone is out of

use, do not give so much trouble as those that are used to complete the transmitter and receiver circuits.

It will be noticed that any one of the springs *c*, *d*, or *e* bears alternately on a rubber block when the hook is in one position, and on a metallic contact on the lever when the hook is in the other position; thus, the spring *c* bears on the rubber block *b* when the hook is depressed and on the metallic knife edge on the short arm *a* when the hook is raised. This change of contact is, however, accomplished without dragging the spring alternately over one and then over the other; that is, the rubber block *b* and metallic knife edge *a* never rub or touch the same part of the spring *c*. Many hooks have been designed that brought about changes in the circuits that neglected this point, and have always resulted in failure, because, in passing from the rubber to the metal surface, a small portion of the rubber would adhere to the metal, thus forming a partially insulated path; again, in passing from the metal to the rubber, the metallic particles from the former would be deposited on the latter, thus forming on it a partially conducting surface. Such sliding contacts as these should be carefully avoided, and this is cleverly done in the Warner switch. Another serious difficulty that often arises in hook switches is that due to cutting between the various contact surfaces. This will invariably occur where a long sliding contact takes place between the lever and the various springs. The amount of energy available for moving the switch is limited by the weight of the receiver, and it frequently happens that where these long sliding contacts take place, the surfaces become so roughened, due to the cutting action between them, that the restoring spring does not have the power to raise the lever when the receiver is removed, or the receiver does not have the power to pull it down again when placed on the hook.

No contact should be made with the lever of a hook switch through the pivot on which the lever moves. If contact with a moving lever is necessary, it may be made through a very flexible spiral of rather small wire, one end of which is soldered to the lever and the other end to a firmly fixed wire,

or terminal of some sort. The ends of the hook levers are now usually ring-shaped and of sufficient diameter to prevent their accidentally entering the aperture of the receiver ear cap and thus bend the diaphragm.

9. Williams Hook Switch.—The hook switch made by The Williams Telephone and Supply Company, shown in Fig. 5, illustrates a type that many companies are now making. The lifting spring *s* is made of tempered steel. There are four springs with genuine platinum contacts, which are said to give a positive electric contact in all climates and under all conditions of moisture and temperature.

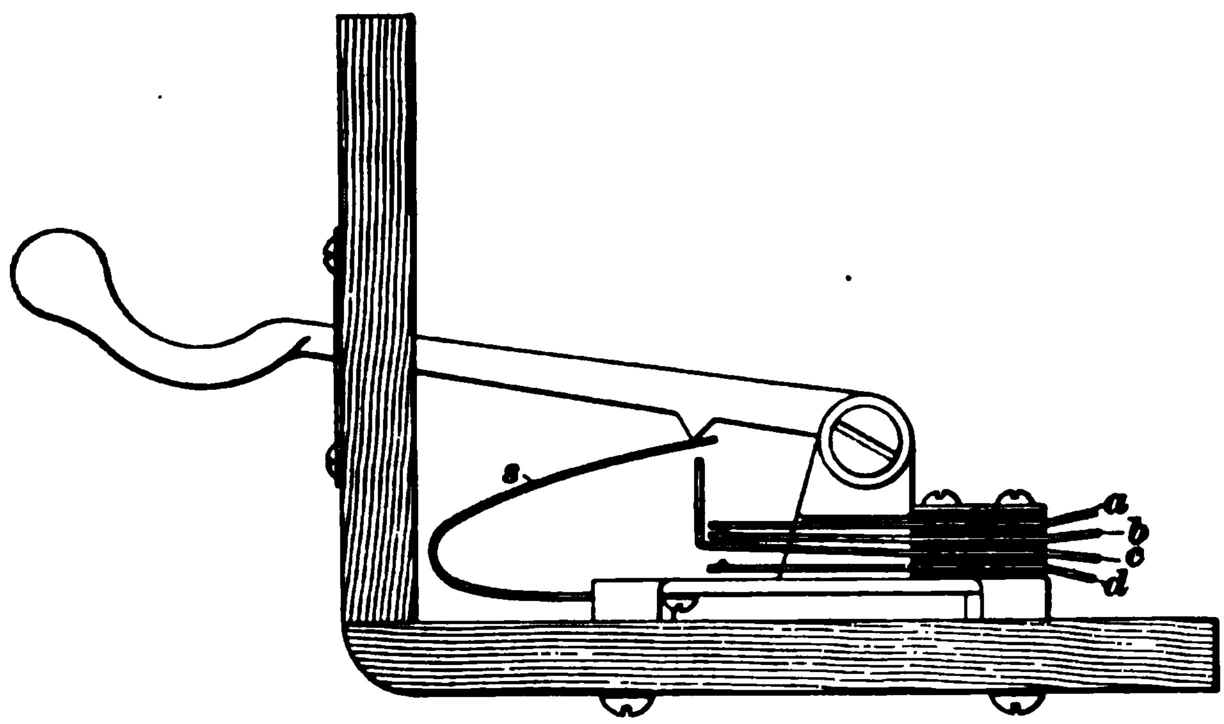


FIG. 5

When the receiver rests on the hook, the springs *d*, *c* are in contact; when the receiver is off the hook, the springs *c*, *b*, *a* are all in contact. No electrical circuit passes through the lifting spring, hinged joint, or the frame, thereby eliminating the possibility of loose contacts, which are difficult to locate. The hook switch is self-contained and can be taken out without disturbing the other parts of the telephone.

10. Dean Hook Switch.—The standard hook switch of The Dean Electric Company is shown assembled in Fig. 6 (*a*) and with the hook lever and part of the contact springs removed in Fig. 6 (*b*). It is self-contained, even to the escutcheon *a* that serves as the means of fastening the switch to the telephone cabinet; thus, no dependence is

placed on the woodwork for the proper operation of its parts. The escutcheon *a* and framework *b* are from one piece of sheet steel formed into shape. The contact springs *c* are mounted on a small metal block *d*, which is, in turn, fastened to a projection *e* of the main frame. In this way, any combination of springs necessary to adapt the switch to different telephone circuits can be assembled and kept in stock, the remainder of the hook switch being interchangeable. The switch springs are made of German

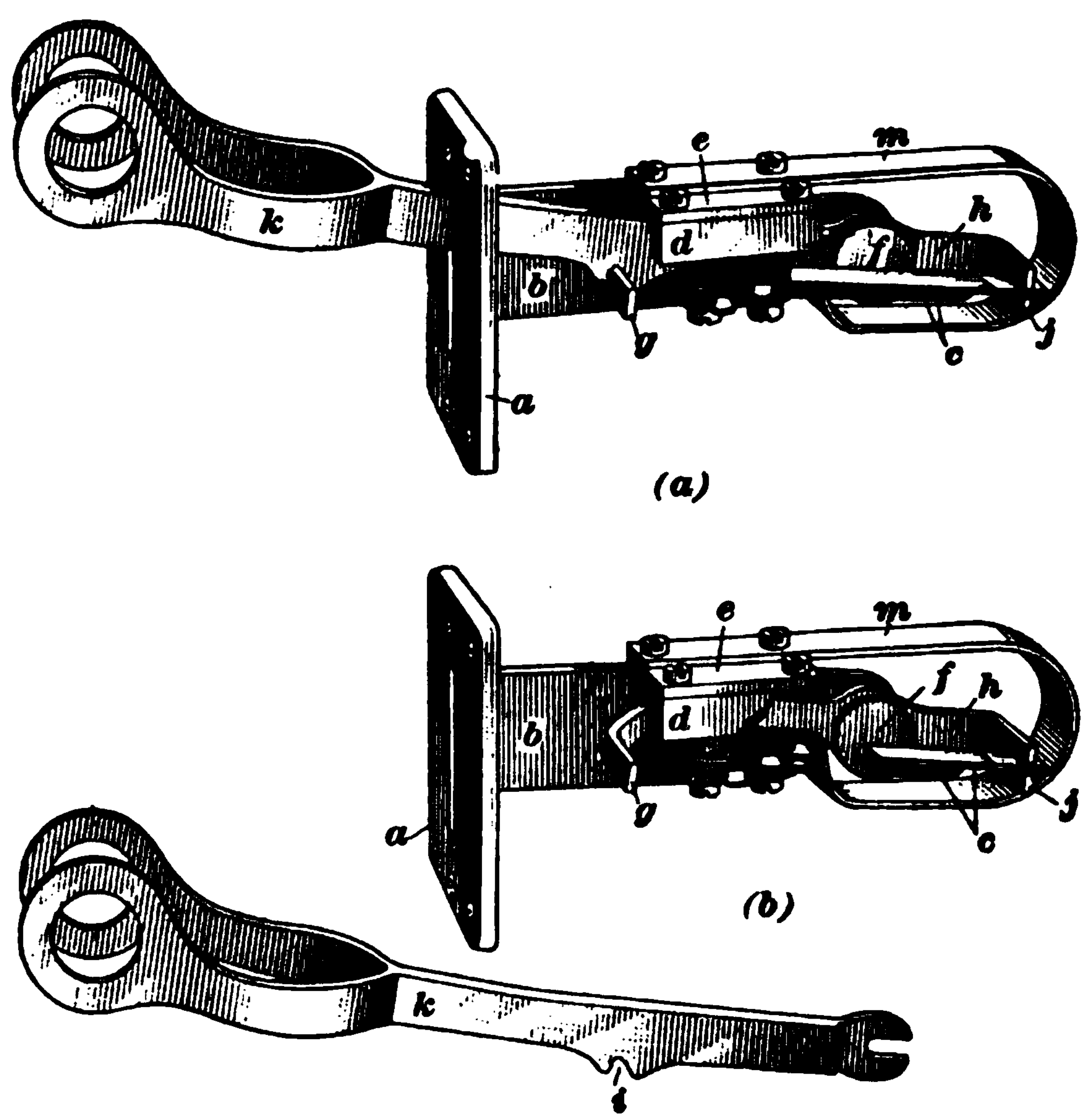


FIG. 6

silver with pure platinum contact points and are insulated from each other and the mounting block by hard rubber.

This switch has a removable hook lever *k* that allows this part of the mechanism to be readily removed from the telephone for convenience in packing and to prevent damage in shipping and handling. When the hook lever is inserted in place, its slotted end straddles the fulcrum *f*, while the finger *g* of the intermediate lever *h* engages the notch *i*, thereby securely locking it in place. The intermediate

lever is pivoted on the stud *f* and is provided with a second finger *j*, which is slotted so as to engage and actuate the contact springs *c*. The main spring *m* of the hook switch has an upward tension directed against the left-hand portion of the intermediate lever *h*, which forces the latter into engagement with the hook lever *k* through the agency of finger *g*. Thus, the one spring serves the purpose of locking the hook lever in place and operating the contact springs when the receiver is removed. When once inserted, the hook can only be removed by opening the lid of the telephone box to reach and release the locking finger *g*, which, when depressed, disengages the notch *i* and allows the hook to be readily withdrawn. The ends of the hook are made ring-shaped and of sufficient diameter to prevent their accidentally entering the aperture of the receiver ear cap and thus denting the diaphragm.

11. Kellogg Hook Switch.—The Kellogg hook switch is shown in Fig. 7 (*a*). The mounting lug, or base, on which all the parts are assembled, and the springs are shown separately at (*b*). The back portion of the base is provided with tapped holes *v*, *v* whereby the entire switch mechanism is mounted with machine screws in the telephone box; this forms the only fastening necessary, as all the parts are mounted on this base. The contact springs, after being assembled, are securely fastened to the mounting lug with two machine screws *o*, *p* and all of them are insulated from the hook lever and frame. The hook *q* fits over the pin *r*, which is rubber-covered. The contact points, which consist of platinum rivets through German-silver springs, have their conical points turned upwards so as to prevent poor electrical connections due to the accumulation of dust and foreign matter. The slight wiping action between the springs also tends to keep the contact points clean while the springs are exposed and open for inspection. The brass, nickel-plated, and polished lever is held in place over the pivot rod by a lock screw *s* inserted from the top, as shown in Fig. 7 (*c*). The mounting lug and slot in the end of

the lever are shown in this figure. While this construction allows the lever to be readily removed and replaced, it also prevents it from coming loose. The lower rear end of the lever has a projection w that forms a stop to prevent the main spring n from forcing the hook above its working position. The main spring n, which is made of German silver to prevent corrosion, acts on the lever, which moves through a

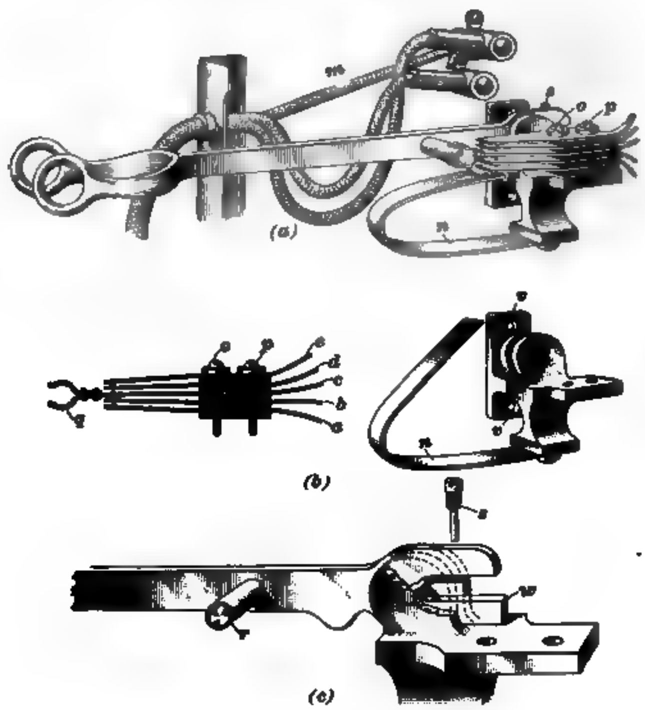


FIG. 7

short distance only, with little or no sliding friction, thus making the action of the hook switch light and positive.

The hook is held down by the weight of the receiver, which causes the contact spring c to make a firm contact with b and b with a; thus, in this position, the three springs a, b, and c are electrically connected together. When the receiver is removed from the hook, the spring n lifts the hook, first

separating the springs *a*, *b*, and *c* from one another and then causing *c* to make a firm contact with *d* and *d* with *e*. In this position, the three springs *c*, *d*, and *e* are electrically connected together. This type of hook switch is used for both central-energy and magneto systems. Evidently the number of spring contacts above or below the spring *c* may be diminished or increased, or some of the springs may be left idle, or the middle spring *c* may have an insulating piece on the top or bottom of its front end so that it will make connection only with the springs below or only with the springs above it. Thus, this type of switch may be made suitable for almost any system.

The weight of the receiver, should it be dropped or left hanging by the cord, is borne by the cord *m* and, therefore, no strain ever comes on the flexible receiver conductors or on the terminal screws to which the latter are connected. The cord *m* is fastened inside the receiver also, so as to take the weight of the receiver off the receiver conductors. There are no exposed connecting posts or screws, either on the receiver or on the outside of the box casing. Hence, there are no exposed metal connections from which a subscriber can receive a shock while handling the receiver or even by touching the hook, as might otherwise happen if the line were crossed with a power or lighting circuit. Furthermore, there are no exposed screws for persons so inclined to meddle with. There are about as many forms of switches as there are manufacturers.

COMPLETE TELEPHONE INSTRUMENTS

12. **A complete telephone instrument** includes all the apparatus necessary for transmitting and receiving both speech and signals, and the auxiliary switching device for bringing either one or the other set of apparatus into use, as desired. The circuits in which these various parts are connected were shown, in a general way, in Figs. 1 and 3. In those figures, however, all details of the circuits were omitted for the purpose of rendering the general principles

involved more clear. Local-battery telephones may be divided into series and bridging instruments.

13. Party Lines.—Such an instrument as that shown in Figs. 1 and 3 is termed a **series-telephone.** It is sometimes necessary to connect more than one telephone instrument to one line, which is then termed a **party line,** or, more properly, a **many-party line.** Obviously, two methods present themselves of connecting telephones to such a line; one being to connect them in series, so that the circuit of the line will pass through one instrument, then through the next, and so on through the entire number. Instruments adapted for such use are termed series-telephones, and are often said to be *looped* in the line. The other method is to connect the instruments in multiple, that is, in such a manner that all the telephones are in parallel branches or bridges between the two sides of the line. The best practice now dictates the parallel connection of instruments with the line; and inasmuch as an instrument so connected forms a bridge between the two sides of a circuit, such instruments are called **bridging instruments.**

SERIES-INSTRUMENTS

14. Complete Post Telephone.—By a **series-instrument** is meant one in which the ringer and the generator, when in operation and therefore not short-circuited by the automatic shunt device, are connected in series with each other across the binding posts of the instrument when the lever switch is in its normal, down position. Both the Post and Western Electric No. 2 circuits are used in series-telephones.

In Fig. 8 are shown the various parts of a complete Post telephone, connected in circuits as they are in actual practice in subscribers' telephone sets. *G* is the magneto-generator, *C* the ringer, *R* the receiver, *T* the transmitter, *H* the hook switch, *B* the battery, and *S* and *P* the secondary and primary, respectively, of the induction coil. *A* and *A'* are the binding posts of the instrument, to which the line wires are attached.

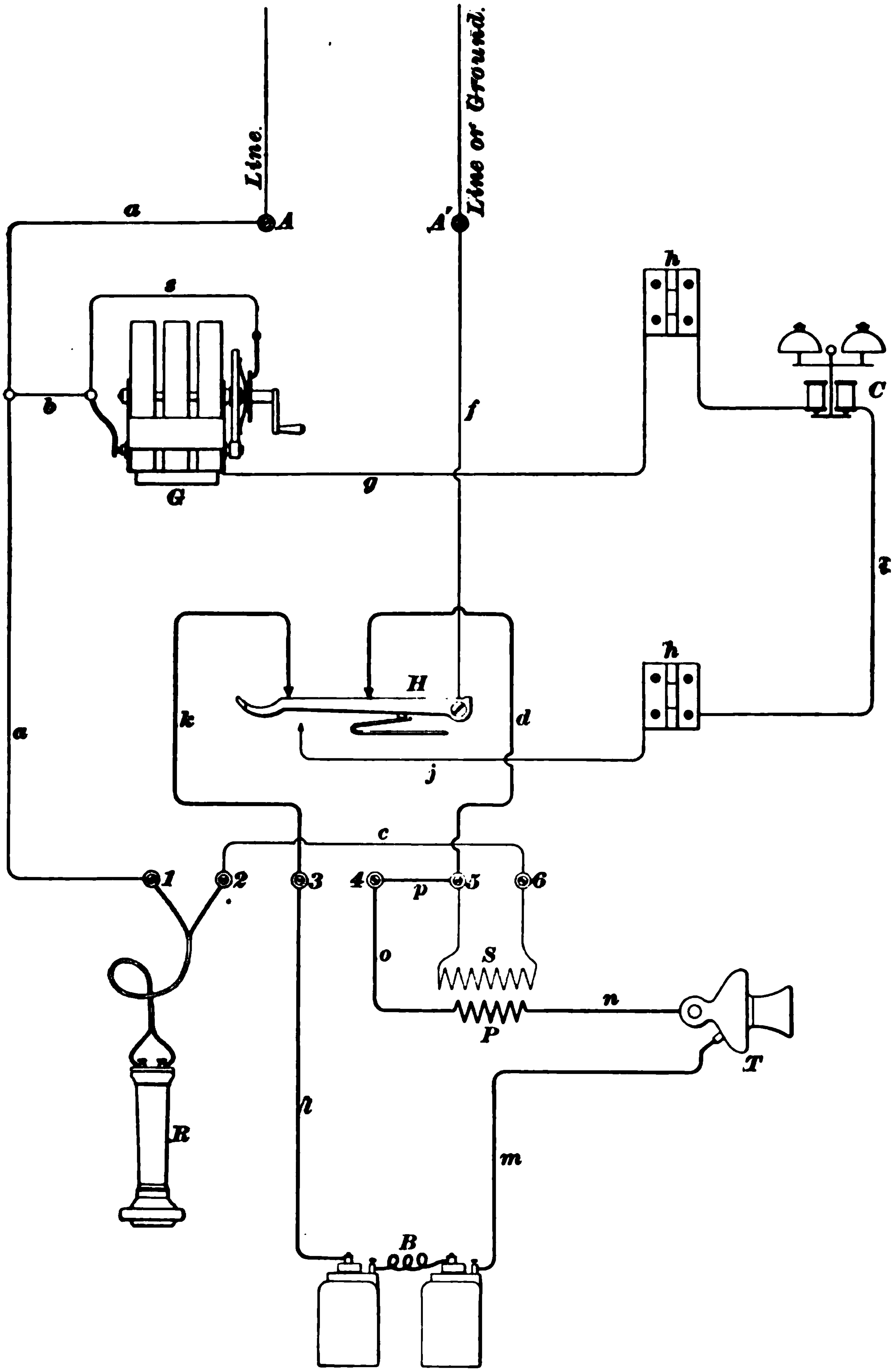

Line.
Line or Ground.
a
A
A'
s
h
C
b
f
G
g
i
H
h
k
d
a
j
c
1
2
3
4
5
6
p
o
S
n
P
T
R
l
m
B

FIG. 8

15. Calling Circuits.—When the receiver is on the hook *H*, the circuit through the instrument may be traced as follows: Starting at binding post *A*, a current will pass by wires *a* and *b* to the armature spring of the generator; two paths will then be presented, one through the armature winding to the frame of the generator and to the wire *g*, and the other through the shunt wire *s*, shunt spring and collar on the generator shaft to the frame of the generator and wire *g*, as before. As the latter path is a short circuit of almost no resistance, especially when compared to that of the armature winding, practically all the current will pass through it. From the wire *g*, the current will pass through the upper hinge *h* on the lid of the box, thence through the coils of the polarized bell *C*, and thence by wire *i*, lower hinge *h*, and wire *j* to the lower contact of the switch. When the lever is depressed, the current will pass through it and by wire *f* to the return side of the line or to the ground, according to whether a metallic circuit or a grounded circuit is used. An alternating current from another station, passing over this path, will cause the bell to ring, and thus give the desired signal. In sending a signal, the circuits will be the same as in receiving one, with the exception that the by-path formed by the shunt wire *s* will be broken, due to the turning of the crank.

The bell used in a series-telephone, being connected in series with the line, should have not only a low resistance, from 60 to 120 ohms, but especially a low inductance. It is therefore wound with few turns of a large-sized wire compared with the winding suitable for a bell in a bridging telephone. Since the inductance is not very large it is possible not only to readily ring, but also to talk fairly well through several series-bells when connected in series in the same line circuit. If the inductance of the bell is too high or there are too many series-bells in the same circuit, the articulation becomes indistinct, weak, and very poor. Series-bells will be further considered in connection with party-line systems.

16. Talking Circuits.—After having sent or received a signal, the receiver is removed from the hook, and the

conditions of the circuits are then as shown in the figure, the signaling circuit being broken at the contact point on the under side of the hook, while two other circuits containing the talking apparatus are closed by the contacts on the upper side of the hook. Starting at binding post *A*, the current coming over the line passes through wire *a*, receiver *R*, wire *c*, secondary winding *S*, wire *d*, upper right-hand switch contact, hook lever, and wire *f* to binding post *A'*. This secondary circuit contains only the receiver and the secondary winding of the induction coil. Another circuit is also closed by the rising of the switch lever containing the battery, the primary winding of the induction coil, and the transmitter. The wires forming the primary circuit are shown by heavy lines, and beginning at the battery may be traced as follows: Battery, wire *m*, transmitter *T*, wire *n*, primary winding *P*, wires *o*, *p*, and *d* to the upper right-hand contact of the lever, through the lever to the upper left hand contact, and by wires *k* and *l* back to the battery.

17. Connections in Generator Box.—It has been customary, merely on account of convenience, to mount the generator, the receiver, and the hook switch in one box, which is usually placed at the upper part of the instrument, the transmitter and battery being put in separate places. In order to facilitate the attachment of the talking apparatus proper, it is customary to place a row of binding posts, *1* to *6*, Fig. 8, inclusive, on the lower part of the generator box. The arrangement of the various parts of the apparatus with respect to these binding posts varies with the make of the instrument; but the custom of the Bell, and most other companies, is to devote the left-hand pair *1*, *2* of the binding posts to the receiver terminals; the center pair *3*, *4* to the terminals of the primary circuit, and the right-hand pair *5*, *6* to the terminals of the secondary of the induction coil.

18. Complete Western Electric No. 2 Telephone. In Fig 9 are shown the various parts of a complete Western Electric No. 2 telephone, connected as they are in practice.

The Williams automatic cut-out is indicated in connection with the generator. The shunt that short-circuits the armature coil, starts at the spring *v*, goes through the shaft *w* of the large gear-wheel to the frame of the generator, and out

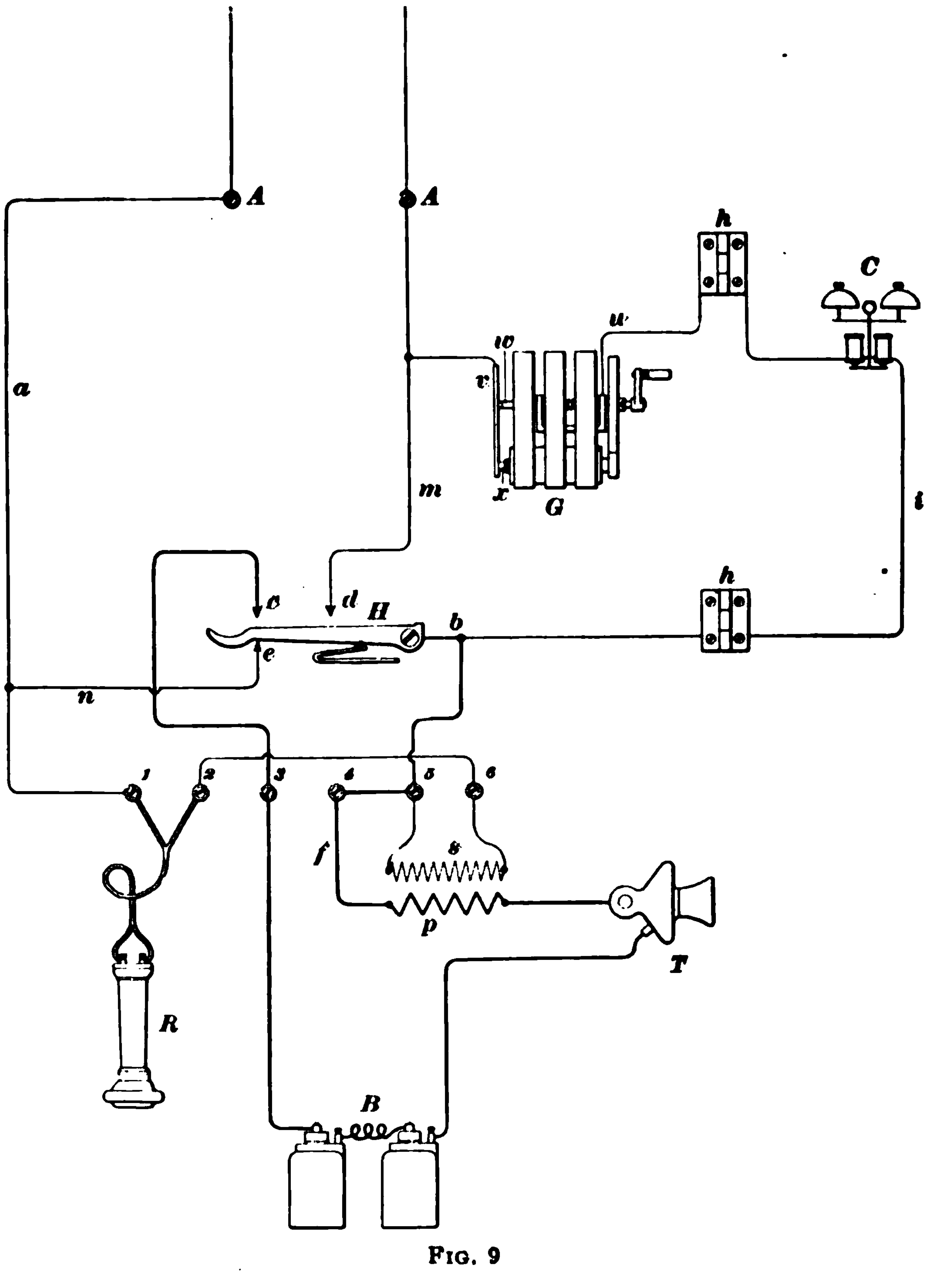


FIG. 9

by the wire *u*. When the handle of the generator is turned, *w* is drawn from the spring *v*, thus opening the armature-shunt circuit, and the path for the current is then from the spring *v* to the insulated end *x* of the armature coil, through

the armature coil and the frame of the generator to the wire *n*. The connections and lettering are exactly the same as in Fig. 3, in which unnecessary details were omitted for the sake of clearness. The reader can readily trace the circuits in the two positions of the hook switch.

19. Series Desk Telephones.—The connections shown so far are those used in the wall type of series telephone instruments. **A series desk telephone,** with the induction coil in the base of the stand, is wired as shown in Fig. 10, *a*, *b*, *c*, *d* being the flexible conductors in the desk-stand cord. The generator and bell are usually placed in a suitable case or box. For a desk telephone, the connections should be arranged to reduce to a minimum the number of flexible conductors in the cord running into the base of the desk stand from the generator bell and battery. This is accomplished by arranging the apparatus and connections as shown in this figure. If the induction coil is not placed in the desk stand, but in the generator box or on a separate wooden base, the same number of flexible conductors will still be required. In the latter case, the flexible conductor *a* will be used to connect one end of the receiver and the secondary winding of the induction coil, and the flexible conductor *b* to connect one terminal of the transmitter and the primary winding of the induction coil.

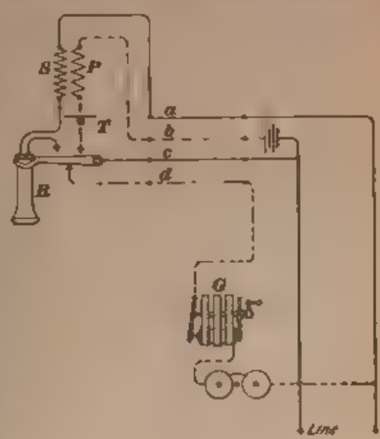


FIG. 10

20. Separate Series-Generator and Bell Boxes. Frequently, the generator and bells are mounted in separate boxes in order to locate each in the most desirable position. In such cases, there is usually provided a so-called terminal block on which a number of binding posts are mounted for

convenience in making the connections. The induction coil is either mounted in the base of the desk stand or on the terminal block. The separate box containing the bell is called an *extension bell*, because the wiring may be extended so as to place the bell in any part of the room or in any other room in the house. The further use of extension bells will be presently considered.

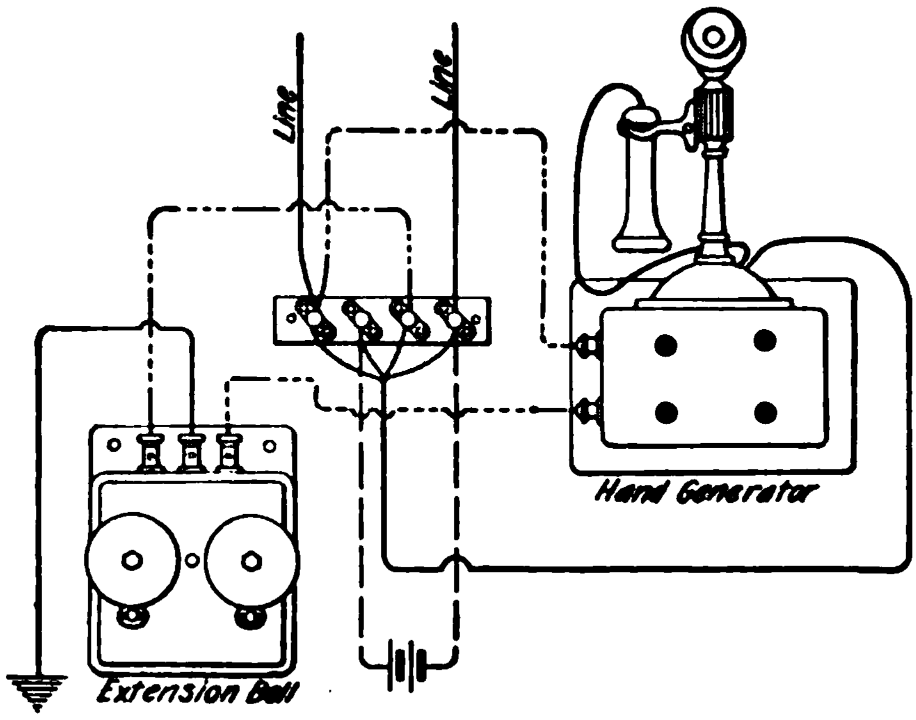


FIG. 11

The method of wiring an office for a series desk set having separate generator and bell boxes and a terminal block is illustrated by the Stromberg-Carlson series desk set shown in Fig. 11. The binding posts on the terminal block and the ends of the flexible cord running to the desk stand are similarly lettered or numbered, so that it is only necessary to connect each flexible conductor in the desk-stand cord to a similarly lettered or numbered binding post on the terminal block. This method of designating how connections should be made is a good one and is considerably used.

21. Hand Microtelephone.—In Fig. 12 is shown a hand microtelephone, which consists of a transmitter, watch-case receiver, and switch, all mounted in one handle that can be conveniently held in one hand with the receiver to the ear and the transmitter mouthpiece in front of the mouth. The switch in the handle can easily be held closed by the same hand that holds the microtelephone. The connections in Fig. 13 show how it may be used as an

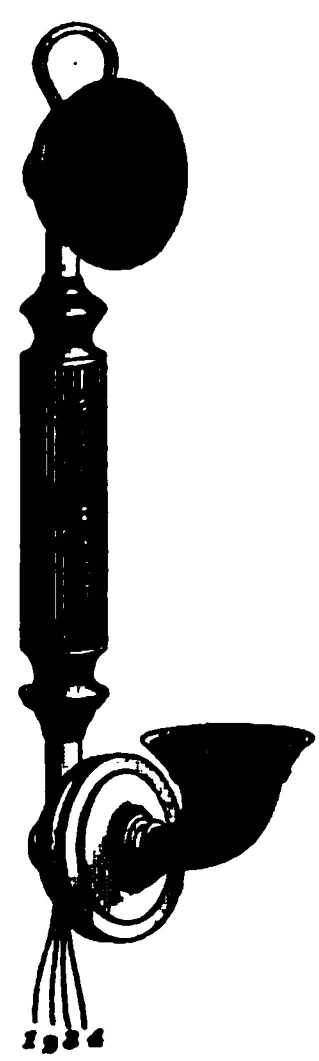


FIG. 12

ordinary series-telephone. When *H* is pressed, *o* parts from *a*, and *o*, *n*, and *m* are connected together; hence, this switch replaces the ordinary hook switch.

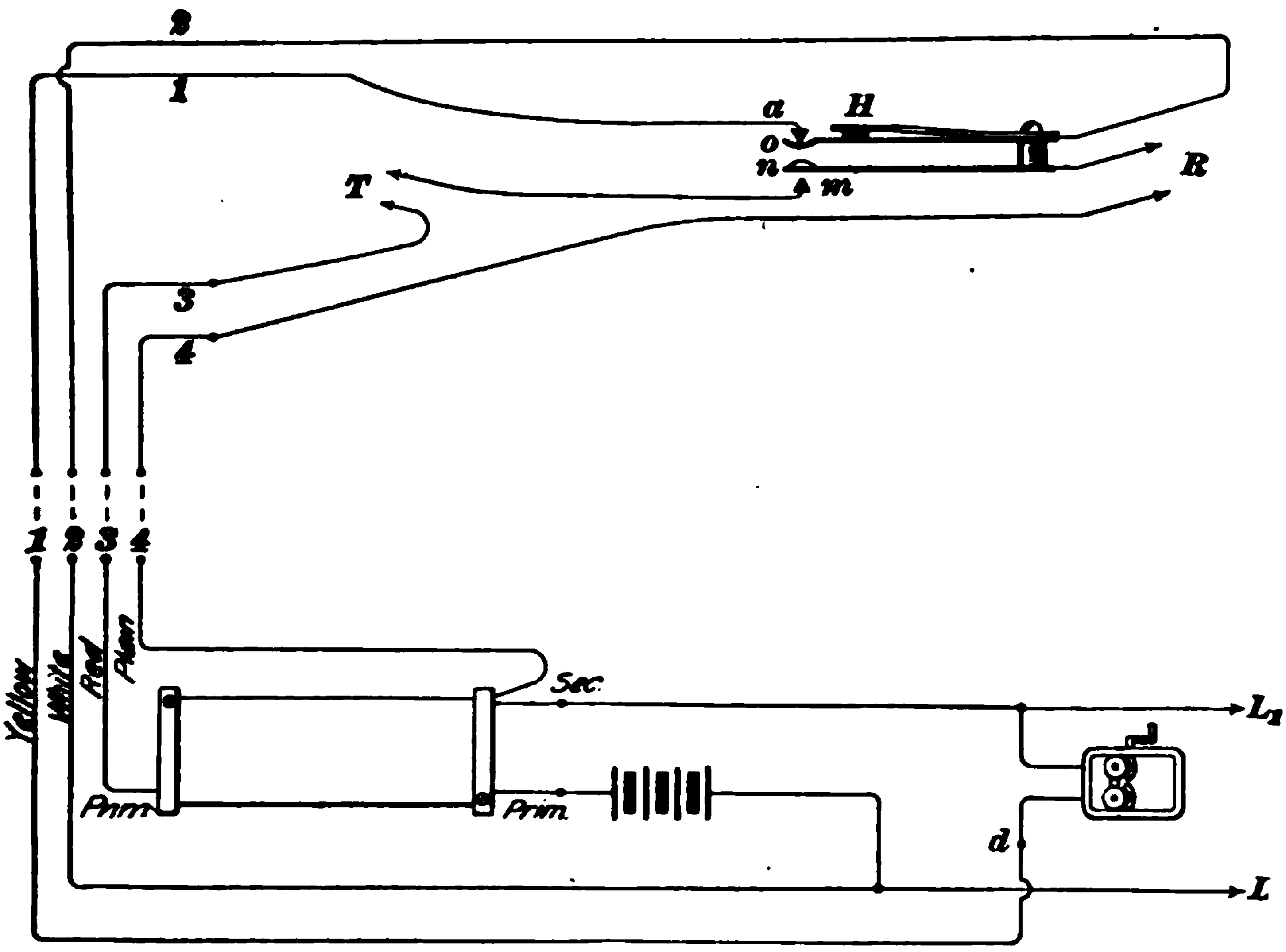


FIG. 13

It may also be wired as a bridging telephone by connecting wire *d* to line *L* and omitting the wire *d–1–a*. The hand microtelephone may be hung up wherever convenient or placed in the pigeon hole of a desk.

BRIDGING INSTRUMENTS

22. Talking Circuits.—In Fig. 14 is shown, in detail, the pieces of apparatus forming a complete bridging telephone instrument properly connected together.

The arrangement of the local circuit is, in this case, identical with that of the series-instrument. The transmitter *T*, the battery *B*, and the primary *P* of the induction coil are connected together in series in a local circuit when the receiver is removed from the hook; while the secondary circuit containing the receiver *R* and the secondary winding *S* of the induction coil are connected in series between the binding posts *A*, *A'*: this circuit is

from binding post *A* through wire *a*, receiver *R*, secondary winding *S* of the induction coil, wire *d*, lever *H* of the hook, and wire *f* to the binding post *A'*.

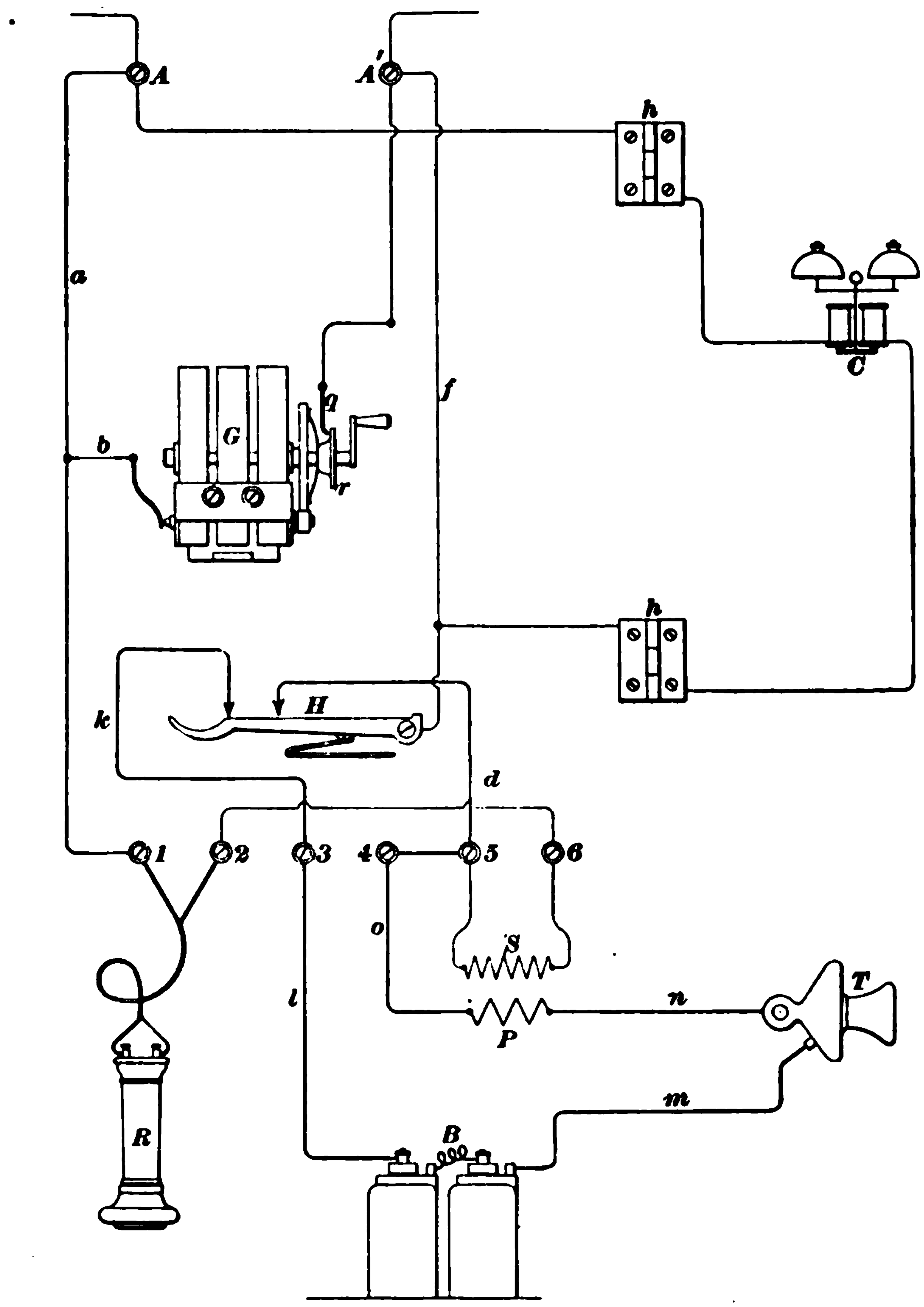


FIG. 14

23. Calling Circuits.—The points wherein the circuits of a bridging instrument differ from those of a series-instrument are found in the connection of the calling apparatus

with the line. In the series-instrument, Fig. 8, the generator and call bell were placed in series between the two binding posts, the circuit being opened by the lower contact point on the switch hook when the receiver was removed. In the bridging instrument, the call bell *C* is in a permanently closed circuit between the two binding posts *A*, *A'*, this circuit being traced from the post *A* through the upper hinge *h*, bell *C*, lower hinge *h*, and wire *f* to the binding post *A'*. This circuit, in some makes of instruments, is never broken. The generator, instead of being in series with the call bell and normally shunted, is connected in parallel with the bell across the two binding posts *A*, *A'*, and is in a normally open circuit. This circuit is closed only when the generator is operated, this being brought about by reversing the shunt mechanism so that it maintains a normally open circuit instead of a short circuit. Thus, in Fig. 14, the spring *q* occupies a position on the opposite side of the disk *r* from that in Fig. 8, the arrangement being such that only when the generator is operated is the circuit closed between *r* and *q*. The circuit may be traced from the binding post *A* through wire *a*, wire *b*, armature of the generator *G*, disk *r*, and spring *q* to the binding post *A'*.

24. Three Bridged Circuits.—It may be said that in bridging instruments, the apparatus is arranged in three parallel circuits between the binding posts. The first of these circuits is permanently closed and includes the ringer; the second is normally open and includes the generator; and the third is also normally open and includes the receiver and the secondary of the induction coil in series. It would appear, at first, that the presence of the ringer magnets as a permanent shunt around the talking apparatus would seriously interfere with the voice transmission. This would be the case were it not that the ringer magnets were wound with a very great number of turns of wire, usually so as to give them a resistance of 1,000 to 2,500 ohms and a high inductance, on account of which an almost impassable barrier

is formed to the passage of the rapidly fluctuating voice currents, so that the transmission is not perceptibly affected.

The impedance of a 1,000-ohm ringer to currents whose

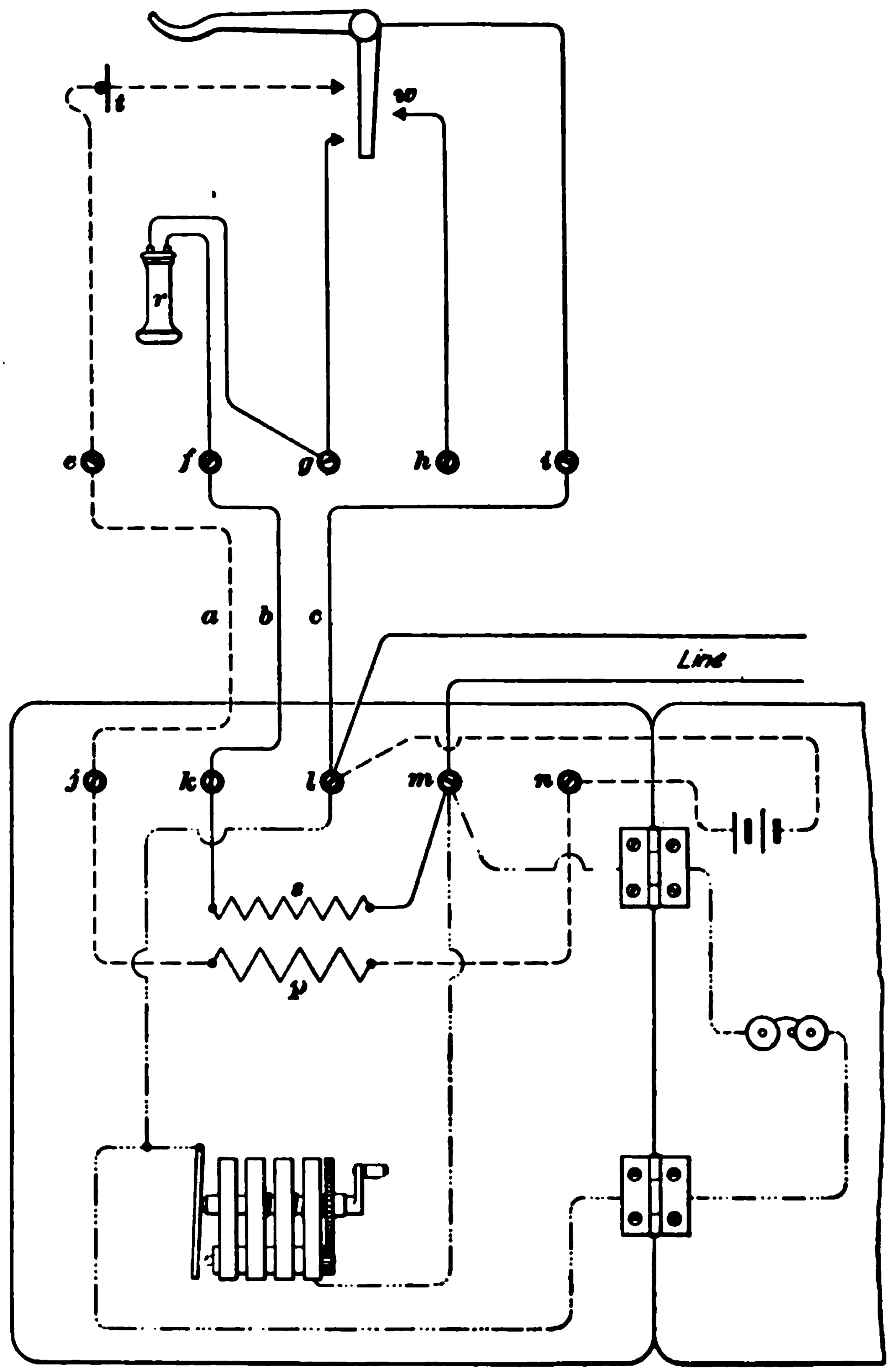


Fig. 15

frequency is about 15, such as produced by the ordinary hand-telephone generator, is about 1,200 ohms, while to the talking current, whose average frequency may be taken

at 300 periods per second, the impedance is a little over 4,000 ohms, and at 600 periods, a frequency quite often attained, it becomes about 8,000 ohms. Thus, it is evident that the ringer acts only as a very high resistance shunt around the talking circuit when that is in use, allowing only an inappreciable part of the talking current to leak through it instead of flowing through the receiver. To the ringing current, however, the impedance is but little larger than its resistance.

The theory of series and bridging instruments and their practical application to party lines will be considered in connection with party lines.

25. Bridging Desk Telephone.—The wiring for an ordinary bridging desk set is shown in Fig. 15. The binding posts *e*, *f*, *g*, *h*, *i* are located in the base of the desk stand. The binding post *h* and contact *w* are not used for this bridging circuit, but are provided as they are required, in an arrangement to be shown presently (see Fig. 16), as well as in series-sets. *a*, *b*, *c* are the flexible conductors, usually made into one cord, connecting the desk stand with the box containing the bell, generator, and induction coil. On the top or bottom of this box are placed the binding posts *j*, *k*, *l*, *m*, *n*. The bell is usually mounted on the lid of the box. The induction coil may be placed in the base of the desk stand without increasing the number of flexible conductors in the desk-stand cord; *a* will then connect *e* to *n*, and *b* will connect *f* to *m*, *p* being between *t* and *e*, and *s* between *r* and *f*. The binding posts *j*, *k* will not be required, or at least not used.

26. Bell Desk Set.—The connections of a desk set used by the Bell Telephone Company on local-battery systems is shown in Fig. 16. The connections vary but slightly from those shown in Fig. 15. As far as practical, the lettering in the two figures is the same. The induction coil is mounted on a wooden base with five binding posts *n*, *j*, *l*, *k*, *m*. One of the cords *b* is connected to an insulated terminal *w* in the foot of the stand, to which is also

attached one terminal of the receiver cord; *c* is connected to one contact of the hook switch, and *a* to the transmitter. The other terminal of the transmitter is connected through the metal work of the stand to the hook switch.

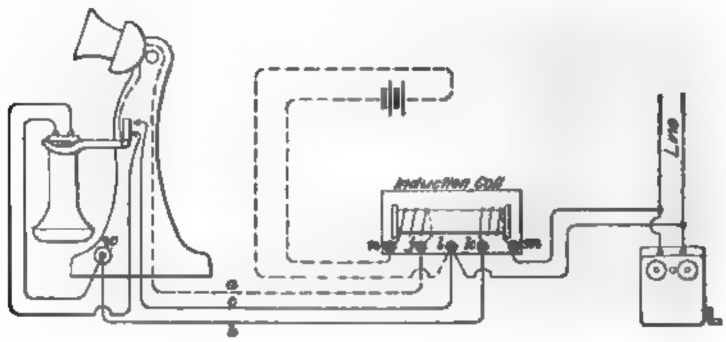


FIG. 16

The two Fuller cells used with this set are placed on a lead-lined tray in a wooden box having a cover. The cells are connected in series, and wires are run from them through two holes in the rear of the box to the binding posts *n*, *l*. This battery box is usually placed on the floor under the desk.

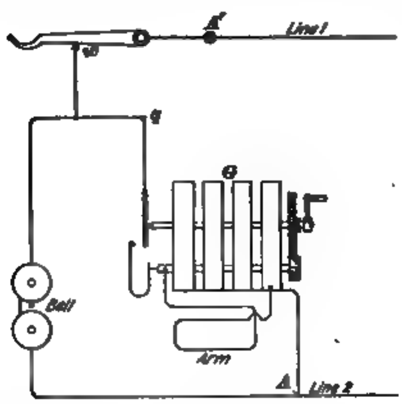


FIG. 17

27. Generators and bells in bridging instruments are connected in various ways. One way was shown in Figs. 14 and 15. Another way, shown in Fig. 17, is to arrange them so that both the bell and generator will be cut out when the hook switch rises. This is especially desirable, but is only necessary for party-line circuits having a number of instruments bridged across the same circuit. It leaves one less bell bridged across the line when the receiver is off the hook, and thus opens one leakage

path between the two sides of the circuit while conversing, but has the disadvantage of an additional contact on the hook switch.

The same object is also accomplished by connecting the generator terminal *q* directly to binding post *A'* instead of to contact *w*, the bell still being left connected between contact *n* and binding post *A*. The transmitter, receiver, induction coil, and battery are connected as shown in Figs. 14 and 15.

28. Dean Bridging Wall Telephone.—The connections used in the bridging wall telephone made by The Dean Electric Company and suitable for use on party lines are shown in Fig. 18. This illustrates another way of connecting bells and generators in a bridging telephone. The connections are the same as in the standard series-telephone made by the same company, excepting that an extra platinum-pointed spring is provided that short-circuits the generator when at rest and short-circuits the bell when the generator crank is turned, thereby preventing the ringing of the bell when the generator is being used. The generator armature winding being normally short-circuited by a platinum contact in the shunt mechanism, is protected from burn-outs through the entrance of foreign currents. This arrangement reduces, by one, the number of bells on a party line that the generator must ring. Moreover, the home bell in the ordinary arrangement takes somewhat more current than any of the other bells, because it has no line resistance in series with it; hence, it is quite desirable to cut it out, especially on long party lines.

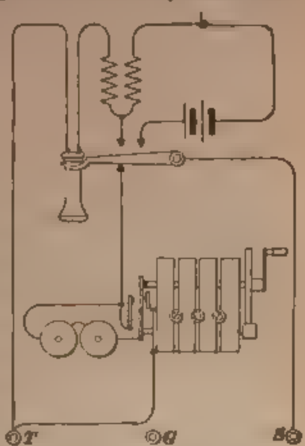


FIG. 18

29. Dean Bridging Desk Telephone.—The connections just shown are modified for use with a desk set so as to reduce to a minimum the number of conductors in the

desk-stand cord. The connections of the Dean desk set, in which the receiver, transmitter, hook switch, and induction coil are mounted in the desk stand, the bell and generator in one box, and four binding posts on a connecting rack, is shown in Fig. 19. At (*a*) is shown a simplified diagram of the connections. A four-conductor cord with regular cord tips at each end connects the stand circuits to the connecting rack. To connect up the set, it is only necessary to join

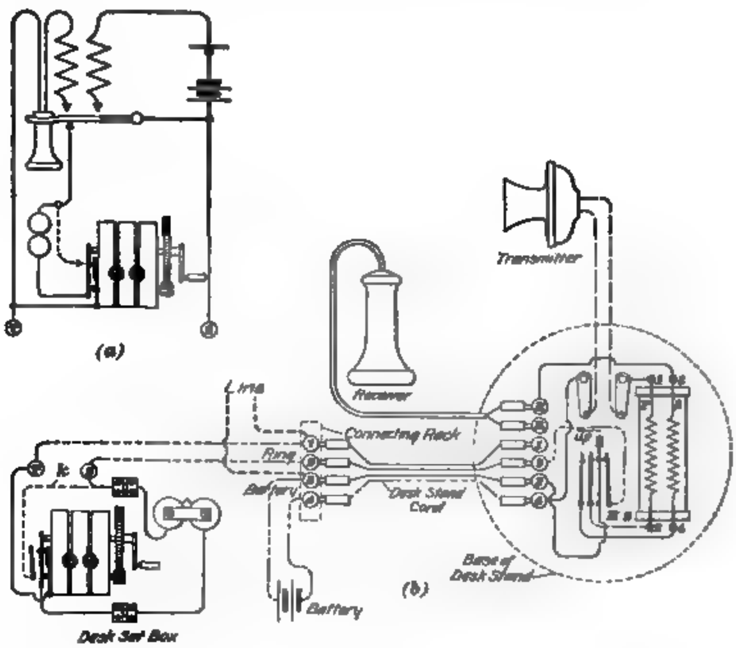


FIG. 19

similarly numbered binding posts by means of the desk-stand conductors and to connect the battery and generator to the pairs of binding posts marked *Ring* and *Battery*, respectively. The Dean series desk set is wired in the same manner, except that the wire *k* in the desk-set box is omitted.

30. Separate Bridging Generator and Bell Box. The wiring for an office set using separate generator and bell boxes, a terminal block, and the generator-bell connections

shown in Fig. 17 or 18, is represented by the Stromberg-Carlson bridging desk set shown in Fig. 20. The binding

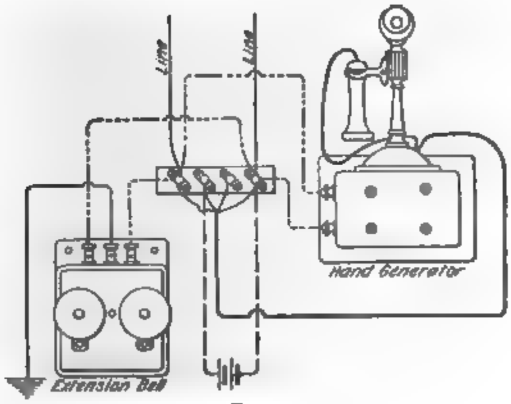


FIG. 20

posts on the terminal block and the ends of the four wires running through the flexible cord to the desk stand are similarly numbered or lettered, so that it is only necessary to connect each flexible conductor in the desk-stand cord to a binding post on the terminal block having the same number or letter.

31. Kellogg Bridging Wall Telephone.—Still another slight modification suitable for use on party lines is shown in connection with Fig. 21. When the generator handle is turned, the spring *s* is pushed away from *r* and into contact with *v*. Since the armature winding is connected between the frame of the generator and through an insulated pin in the end of the shaft with the spring *v*, the generator is cut in and the bell is cut out when the generator handle is turned. Thus, the bell and

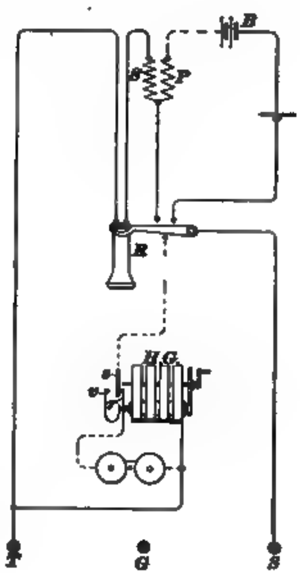


FIG. 21

generator are not only cut out by the rising of the hook switch, but the bell is also cut out when the generator handle is turned. Therefore, the subscriber's own bell never rings when he turns his generator, a feature desired by some persons, and furthermore, this arrangement reduces, by one, the number of bells on a party line that the generator must ring.

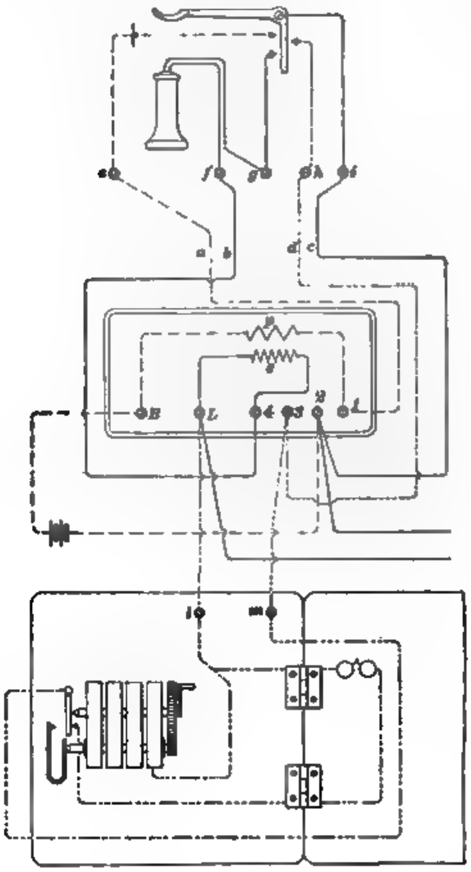


FIG. 22

32. Kellogg Bridging Desk Telephone.—The arrangement just shown is usually modified for use with a desk set so as to reduce to a minimum the number of flexible conductors in the desk-stand cord. The connections for a desk set, when the desk stand contains the receiver, transmitter, and hook switch, the generator box contains the generator and bell, and the induction coil is mounted on a separate connecting rack along with the necessary number of binding posts, are shown in Fig. 22. Four flexible conductors *a*, *b*, *d*, *c* in the desk-stand cord connect the terminals *e*, *f*, *h*, *i* in the base of the desk stand with binding posts, *1*, *4*, *3*, *2*, respectively, on the connecting rack. The line wires, battery

wires, and generator-box terminals *l*, *m* also connect with the proper binding posts on the connecting rack. The bell and generator are cut out when the hook switch rises and the bell is cut out when the generator handle is turned. The box containing the bell and generator is usually mounted under or at the side of the desk, whichever the subscriber prefers. The same number of flexible conductors would be required in the desk-stand cord if the induction coil, instead of being mounted on a connecting rack, were placed either in the base of the desk stand or in the generator-bell box. In either case all the binding posts required, outside of the desk stand, could be mounted on the generator-bell box.

33. Generator, Bell, and Induction Coil Separately Mounted. The wiring of an office when the generator and bell are mounted in separate boxes and the induction coil on a connecting rack is the same as shown in Fig. 22, except that the bell and generator are mounted in separate boxes, as shown in Fig. 23, and connected simply in parallel circuits, as shown in Fig. 17. The battery is placed on the floor under the desk or in any other convenient place.

EXTENSION BELLS

34. All bells used in connection with a telephone, except the bell in the telephone instrument or generator box, are

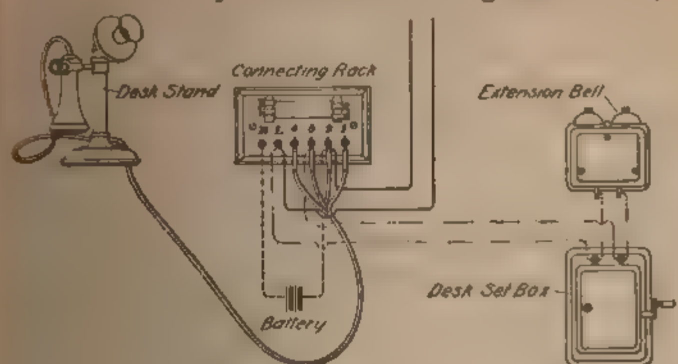


FIG. 23

termed **extension bells.** They are used so that telephone

signals may be received in places where it is not desired to locate the telephone. The extension bell rings whenever the telephone bell rings. Moreover, in noisy power houses and factories the ordinary telephone bell may not ring loud enough to be heard, in which case a loud-ringing extension bell may be used. Ordinary extension bells can be used in connection with either series or bridging telephones, but the extension bell should have exactly the same resistance (which implies also the same number of turns) as the telephone bell with which it is to be used.

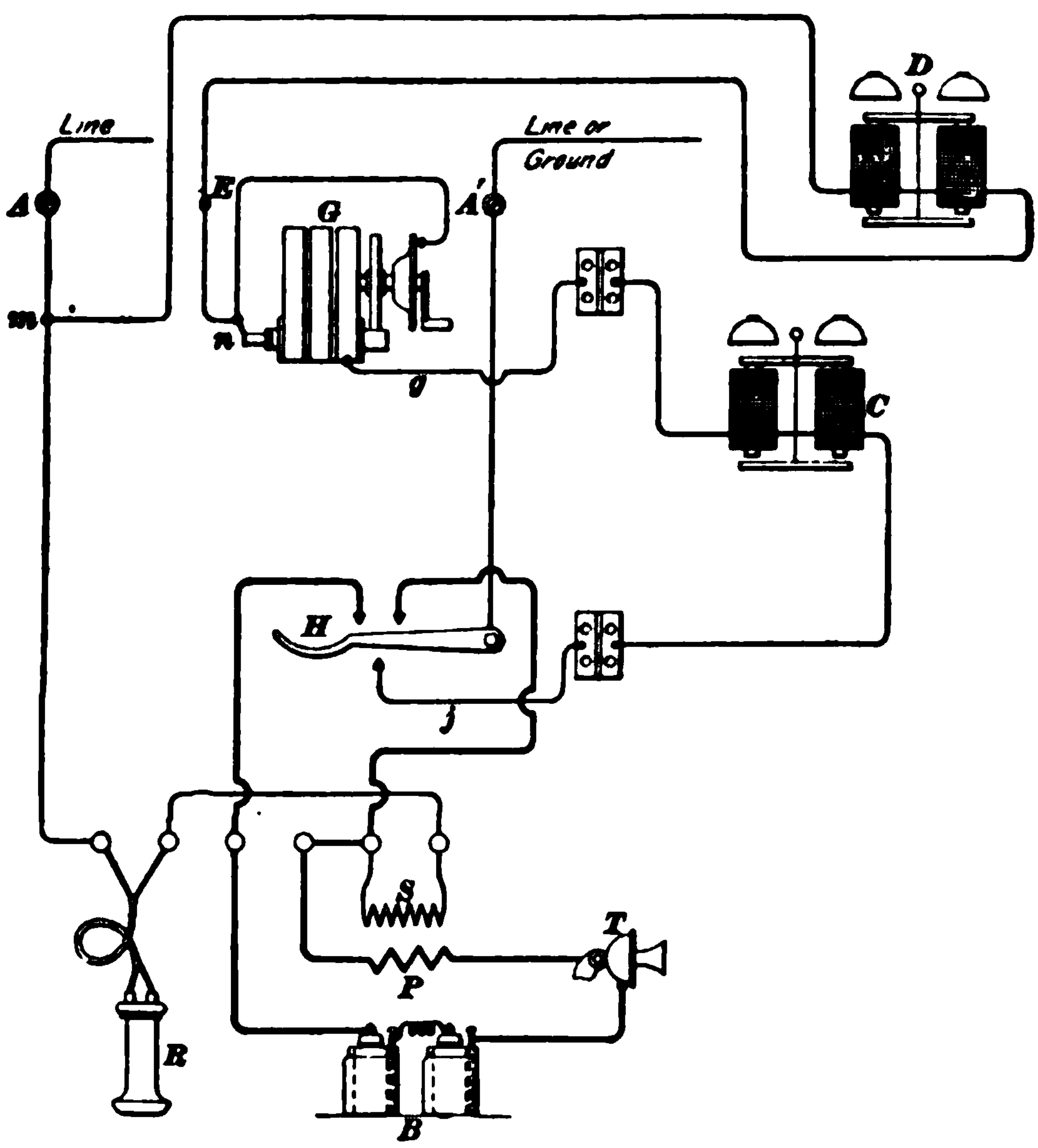


FIG. 24

35. Series Extension Bell.—Fig. 24 shows the proper way to connect an extension bell *D* to a series-telephone in which the Post circuit is used. *A*, *A'* are the usual binding posts to which the line wires are attached. The extension bell *D*, which should have the same resistance and preferably be of the same make as the telephone bell *C*, is connected in the circuit by cutting the wire that would otherwise connect *m* to *n*. An extension bell must never be connected in

the line circuit in series with a series-telephone, because then the talking current, when the telephone is in use, would have to pass through the extension bell, whereas, by this arrangement, both the telephone and extension bells are cut out of the circuit when the receiver is off the hook. Series-telephones are occasionally provided with an extra binding post at *E*, which would be connected by a wire on the top of the instrument to binding post *A* when no extension bell is used.

Fig. 25 shows the proper way to connect the extension bell *D* to a series-telephone, in which the Western Electric

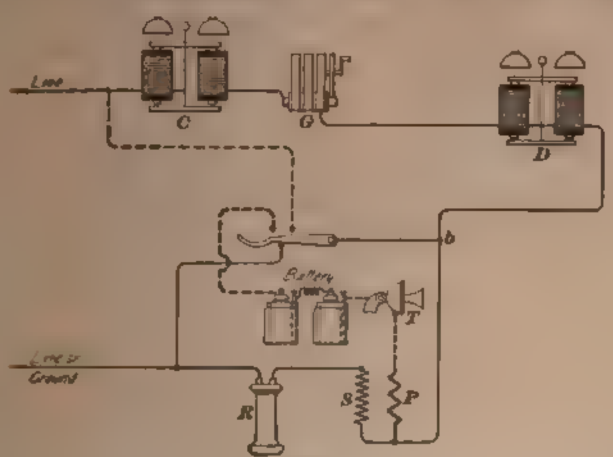


FIG 25

No. 2 circuit is used. The generator *G* would be connected directly to the point *b* if no extension bell were used.

Although the use of more than one series extension bell should be avoided if possible, nevertheless, if more are necessary, they must be joined in series in that part of the circuit where the one extension bell is now shown in Figs. 24 and 25, so that the telephone and all extension bells and the generator will be cut out of the circuit when the receiver is removed from its hook.

36. Bridging Extension Bells.—It is a very simple matter to connect extension bells to bridging telephones. The extension bell, which should be of the same resistance

(and preferably of the same construction) as the bridging telephone bell, may be bridged across the line circuit at the most convenient point. Two bridging extension bells *M*, *N* are shown in Fig. 26 properly connected across a bridging-

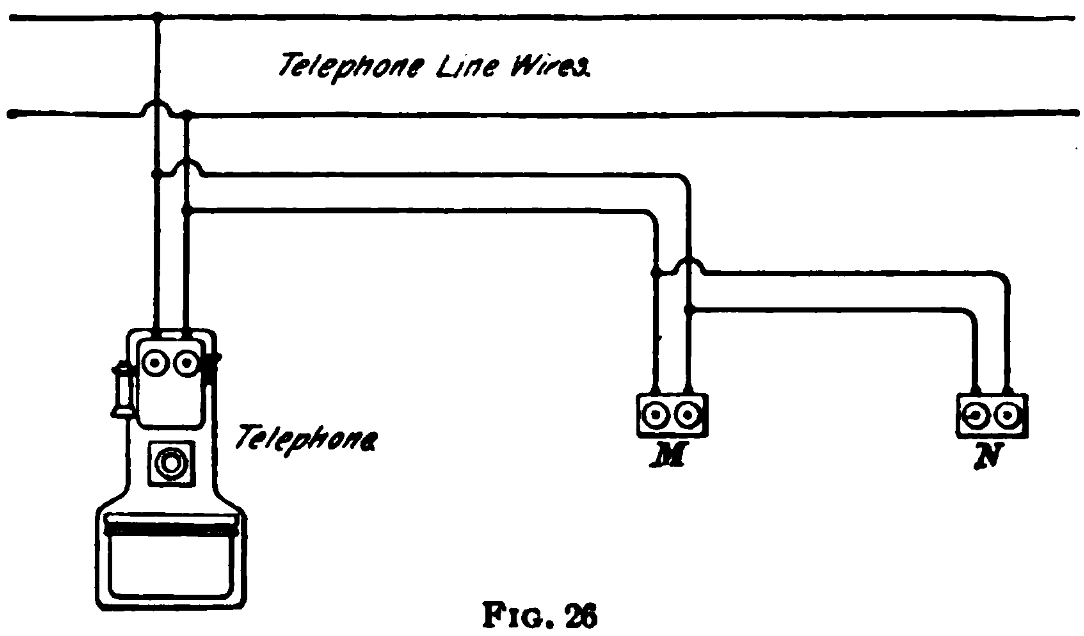


FIG. 26

telephone circuit. When bridging telephones are connected on ground-return circuits, the extension bells are connected between the one line wire and the most convenient ground connection.

CIRCUIT-CLOSING DEVICES

37. Loud-Ringing Extension Bells.—Where a loud-ringing bell is necessary, a special loud-ringing extension bell or an arrangement that will close a local circuit containing a battery and a loud-ringing vibrating bell may be used. The most natural way to accomplish this purpose is to connect an ordinary telephone switchboard annunciator with the telephone circuit in the same manner as an extension bell. The annunciator, as in the case of extension bells, must be of about the same resistance as the telephone bell. Furthermore, with series-telephones the annunciator must be connected in the same part of the circuit as the extension bell, as shown in Figs. 24 and 25. When annunciators are used with bridging telephones, they should be connected across the line circuit, as explained in connection with Fig. 26.

An ordinary switchboard annunciator is usually so arranged for night service that its shutter will close a local circuit when it falls, and the local circuit will remain closed until

the shutter is restored by hand to its normal position. An annunciator joined between a bridging telephone line and the ground, which is here used as a return path for the telephone circuit, is shown in Fig. 27. The local connections are also shown in this figure. When the shutter S falls, the spring t is pressed into contact with the pin u by the heel projecting from the bottom of the shutter. The spring t and contact pin u form the terminals of a circuit containing a battery and an ordinary vibrating bell, and the bell is therefore sounded whenever the shutter falls. Moreover, the bell will continue to ring after the shutter has fallen until it is pushed

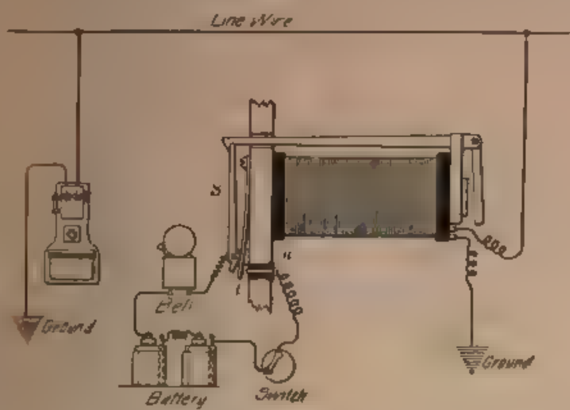


FIG. 27

up by hand. It is convenient to have a switch in the local circuit in order to leave the circuit open at night or at other times when no one is around to restore the shutter if it falls.

Evidently, as large a bell and as powerful a battery as necessary may be used. Furthermore, any number of vibrating bells may be connected in series in the same circuit, provided that the vibrating devices that make and break the local circuit at the bells are all short-circuited, except at one bell. The make-and-break device on one bell will interrupt the current for all the bells. If more than one such device is allowed to work, they are apt to interfere with one another, and cause the bells to ring poorly.

38. The magneto circuit-closing attachment made by The Holtzer-Cabot Electric Company is shown in Fig. 28 with its cover removed. It is a sensitive relay operated by the current from a magneto-generator. When the armature *a* is attracted, the hook in it releases the lever *h* and the spring *s* closes a local circuit at *d*, which remains closed until the device is reset by pulling down the handle *h*. This causes the end of the lever *c* to force the armature to its proper position and hold *h* in place. This device may be used to close a local circuit containing a battery and bell or a small electric lamp, or to control other electrical devices at a distance. The circuit is not carried through any pivots or loose joints and the coils may be obtained wound to almost any resistance or number of turns desired.

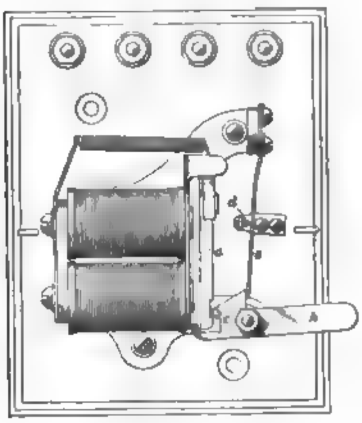


FIG. 28

39. Extension-Circuit Closer.—The objection to annunciators and extension bells that have their magnet coils connected in series with the telephone bells, or bridged across the line circuit, is the fact that on party lines where there are already a number of telephone bells, these extra bell magnets interfere, more or less, depending on their number, with the talking qualities of the circuit. A device that overcomes this objection is the extension-circuit closer manufactured by the Garton-Daniels Co. This device is shown in Fig. 29 attached in the proper position on the front of the telephone box. The least movement of the bell clapper moves the vertical lever *c*, which then raises the latch *a* enough to allow the shutter *b* to fall. When the shutter falls it rests against a contact button *e*, thereby completing the circuit between the two binding posts *m* and *n*, and causing the extension bell to ring until the shutter is

restored, by hand, to its normal upright position. This is a simple mechanical device, with no magnets in the line circuit to interfere with the efficiency of the telephone, or to be burned out by lightning discharges or by current due to crosses between the telephone and electric light or power lines. There is a switch *d* by means of which the extension-bell circuit may be opened.

This device is attached to the front of the magneto-box, by means of the screw *s*, in such a manner that the upper end of the lever *c* rests against the bell clapper, as shown at *i*. By twisting the device from right to left, the position may

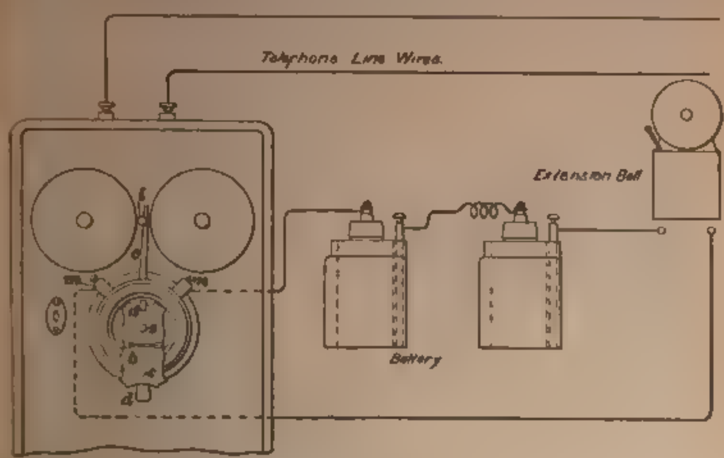


FIG. 29

readily be found where the stroke of the bell clapper will lift the latch whether the clapper stops at the right or left end of its stroke. The screw should then be tightened securely, so that jarring or the falling of the shutter will not change the adjustment.

40. Extension-Circuit Ringer.—With ordinary telephone annunciators, having a magnet connected in the tele-phone circuit, or with such an arrangement as the one just described, in which the falling of a shutter closes a local vibrating-bell circuit, the bell continues to ring until the shutter is restored. Hence, with party-line telephones it is

impossible to distinguish one call from another because the extension bell, instead of giving distinct long and short rings like the telephone bell, gives only one continuous ring. This is a serious objection to such arrangements on party-line telephones.

A device made by the Garton-Daniels Co., that is called an **extension-circuit ringer** and overcomes this objection, is shown in Fig. 30. This device closes the extension-bell circuit only while the telephone bell is ringing, opening it automatically as soon as the telephone bell comes to rest, thus reproducing the exact signal made by the telephone bell.

Fig. 30

The essential feature of this device is a balance wheel *a* and a flat spiral spring *e*, the arrangement so far, although much heavier, resembling the balance wheel and hair spring of a watch. When the bell clapper on the telephone vibrates, it pushes against the lever *c*, which, in turn, presses against a pin *v*, thereby turning the balance wheel *a* to the left, or counter-clockwise. On the balance wheel *a* is a pin *w* that does not normally touch the flat spring *r* that is fastened to the insulated piece *o*.

When the clapper of the telephone bell moves to the right, the pin *w* turns with the wheel and touches the spring *r* and so closes the extension-bell circuit. The hair spring attached to the balance wheel throws the wheel back to its original position after each stroke of the lever. The rapid vibrating of the bell clapper on the magneto keeps turning the wheel over so that the circuit is immediately closed again after being opened by the action of the hair spring; hence, the circuit is closed practically as long as the

lever *c* is kept vibrating. When the clapper of the telephone bell comes to rest, the hair spring always opens the extension-bell circuit. This device is particularly adapted for use on series or bridged party lines, where an ordinary telephone annunciator or other device that closes a local circuit by the falling of a shutter or a similar contrivance would not be satisfactory.

41. The extension-circuit ringer is fastened on the telephone box, as shown in Fig. 31, first by one screw, so that the pendulum, as *c* is called, is practically vertical, and the top of the pendulum should be held against the bell clapper by the action of the hair spring. The device may be adjusted by twisting it to the right or left, so that the pendulum will return to such a position, when the bell clapper comes to rest, that the local-bell circuit will be open, whether the clapper stops to the right or left of its stroke. By twisting the case to different positions, and ringing the telephone bell, the proper position may be readily found. By means of a second screw, it may be permanently fastened in this position.

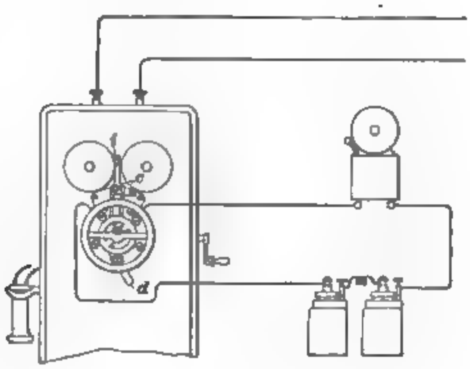


FIG. 31

A local circuit, containing an ordinary vibrating bell and a battery, is connected to the binding posts at the top of the device, and the screws *m* and *n* hold in place a bridge piece forming one bearing of the wheel. The method of connecting the local circuit is shown in Fig. 31. By means of the switch *d*, the local circuit may be opened or closed so that the extension bell will ring or not, as desired. Neither of the two devices last described diminish the loudness of the telephone bell to any appreciable extent.

A telephone company that has tested this device reports that it operates satisfactorily, even when the telephone bell is rung through a circuit of 3,000 ohms, which is quite a good proof of the delicacy of operation of the device.

TELEPHONE INSTRUMENTS

SUBSTATION APPARATUS

DETAILS OF TELEPHONE INSTRUMENTS

WIRING

1. The manner in which a telephone is "wired up" plays an important part in the efficiency of the instrument. The greatest precaution should be taken that none of the wires lie so close together as to form crosses between them, and breaks in the various circuits should be guarded against. The method of wiring the inside of a telephone box by the use of small staples has been extensively used and may give good results, provided that it is carried out with sufficient skill and care. A good grade of insulated wire should always be used, and two wires should never, under any circumstances, be placed under the same staple. It not infrequently happens that two staples over different wires, although apparently out of contact, make contact with each other under the surface of the wood, and thus form crosses that it is often very difficult to locate; this should be guarded against. The use of staples is no longer considered good practice, and some refuse to accept instruments so wired, but will allow the use of tacks to hold an insulated wire in a groove.

2. Lacing Method of Wiring.—In a plan of wiring recently adopted by several companies, the wire is not insulated, and is held in position by being laced back and

forth through the backboard of the generator box. By this method, it is very easy to draw the wires tight before soldering them to their proper terminals.

3. Cleat Wiring.—Another method is by the use of wooden cleats placed at the intersection between the backboard and the sides of the generator box, the cleats being provided with suitable grooves, through which the wires are led. These cleats are held in position by screws, and may be removed readily in case of needed repairs.

4. Groove Wiring.—Probably the latest method of wiring used by reliable manufacturers of telephone instruments consists in placing tinned copper wire, not smaller than No. 20 B. & S., in grooves made in the backboards or bases; these grooves are then filled with wax which covers the exposed or unfinished part of the woodwork, which might otherwise absorb moisture and cause trouble. When exposed, or where wires cross one another, they are covered with a woven sleeve made of a double braid of cotton filled with shellac. The use of soft-rubber tubing, which gets hard and brittle, should never be allowed for this purpose.

All joints are soldered, with the exception of the generator connections, which are often made by means of special screw, or binding-post, terminals, so that the generator may be removed for inspection or repair without disarranging the wiring in the box, or *cabinet*, as it is also called.

5. Soldering Fluxes.—The easiest flux with which to solder iron, copper, and tin is probably the so-called soldering acid, which is a saturated solution of zinc in hydrochloric acid, or, as it is sometimes called, muriatic acid. It can readily be made by adding zinc to a solution made of equal parts of hydrochloric acid and water until no more zinc will dissolve. The solution of zinc chloride thus made is usually strong enough for most purposes if further diluted with an equal amount of water. This solution is rubbed on the parts to be soldered. A lump of sal ammoniac is frequently used in workshops, on which to rub, clean, and tin the end of the soldering iron.

A better soldering fluid, especially for use in soldering telephone, telegraph, electric light and power conductors inside buildings, consists of a saturated solution of zinc chloride, five parts; alcohol, four parts; glycerine, one part; this fluid will leave no acid on the wire.

Soldering paste may be made from Canada balsam with a small portion of sal ammoniac mixed with it, so as to make a stiff paste. The soldering sticks may then be made by adding resin enough to the above mixture to harden it, so that the soldering copper will melt and cause it to flow on the parts to be soldered.

A soldering stick, which the makers claim will neither corrode wire nor affect insulation, is made by the L. B Allen Co., of Chicago. It is a good substitute for resin, acids, and soldering salts. Where insulation is removed from a wire, the makers claim that it is not absolutely essential to scrape the wire when the soldering stick is used. It comes in round sticks 6 inches long and 1 inch in diameter.

The same company also makes a soldering paste and non-corrosive soldering salts. The soldering paste is suitable for soldering in places hard to get at, as in switchboards and for large electric-light-wiring joints. It may be placed on the joint with a cloth or the finger, or the solder may be simply dipped into the paste before applying to the joint. The soldering salts are intended more for use in the shop, where a cheaper flux than the soldering stick or paste must be used.

A flat, ribbon-like solder, with a core of resin correctly proportioned to the amount of solder present, is used by the Kellogg Switchboard and Supply Company in making telephones and in switchboard assembling work.

6. Soldering Joints.—All joints, either between two wires or between a wire and a metallic surface, such as a spring or hinge, should be carefully soldered; but the flux used should be resin or some other non-acid soldering salt, because when acid is smeared over the surfaces of the metal and the wood, it causes them to present an unsightly

appearance; and, what is more serious, the acid frequently corrodes the wires to such an extent as to entirely break the circuit.

7. Hinge Joints.—As the ringer is usually mounted on the cover of the generator box, it is necessary to provide flexible connections to it. These are usually made through the hinges of the box, and unless certain precautions are taken, the contact through them is apt to become very poor. To remedy this, many companies use the device shown in Fig. 1, in which *a*, *a'* are clips of spring metal, each secured under one of the screws holding one side of the hinge in place. When the hinge is closed, these clips are pressed firmly together, thus securing a firm connection.

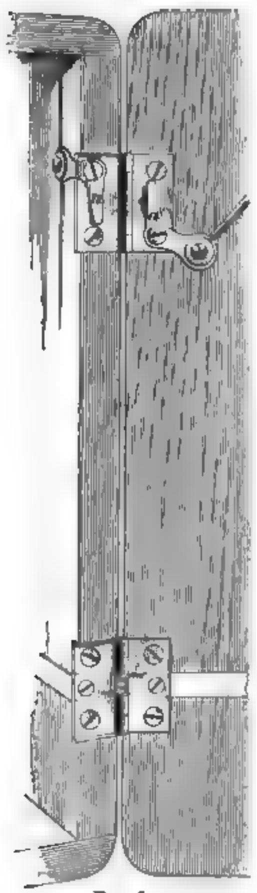


FIG. 1

Some companies use a small spiral spring, as shown on the lower hinge in this same figure, with both ends riveted and soldered to the halves of the hinge.

Another way of making a hinge-joint connection is by means of a piece of a flexible conductor, such, for example, as lamp cord, which is attached rigidly at one end to the inside of the box, and at the other to the inside of the cover, and soldered to the other wires or else fastened firmly under binding posts or screws.

8. In permanently securing wires to binding posts, as on the inside of the box, the custom has been to clamp the wire between two copper washers by means of the screw that

passes through the wood of the box and holds the binding posts in position. This method is not altogether satisfactory and frequently causes open circuits, by reason of the fact that wood often shrinks under the pressure of the screw and thus loosens the contact between the washers and the wire. A better method is to solder the wire directly to the binding post or to the screw entering the binding post; and in doing this, care must be taken that the wood is not burned to such an extent as to loosen the post. Where the screw passes through metal instead of wood, it is safe to make the connection without soldering, because there is no danger due to shrinkage.

FITTINGS

9. Binding Posts.—Binding posts are used for joining wires where it is probable that the conductors must some-

FIG. 2

times be disconnected; therefore, they must be capable of securely holding another wire in such a manner that the connection will always be firm and not liable to work loose from any cause whatever. The manner of connecting wires permanently with the binding posts that are to form their terminals has already been described. The binding posts of receivers are, perhaps, subject to the most severe use, due to the constant handling of the receiver.

One form of binding post is shown in Fig. 2, in which the base of the posts is formed of a sheet of spring German silver, having two upwardly turned spring clips s, s, provided on their tops with notches in which the receiver-cord tip or wire may rest. The screw b, engaging the nut n on the

opposite side of the material to which the post is to be attached, is provided with a large, flat head, adapted to bind firmly against the cord tip or wire, and to press it more securely against the clips *s*, *s*. As the screw is forced down, the clips yield, owing to their elasticity, until finally the head of the screw comes into contact with the upwardly turned lug *p*, also on the base plate, against which it engages by friction, thus preventing its working loose. The firm connection made by this post will be independent of the shrinkage of the wood or other materials through which it passes, as long as its shrinkage is not so great as to allow the clips *s*, *s* to resume their normal position. The space due to the shrinkage of the wood will be taken up by the elasticity of the clips, which will still clamp the chord tip firmly against the head of the screw.

10. In fastening a wire to an ordinary binding post, care should be taken not to allow the free end to overlap, as shown at *c*, Fig. 3 (*a*); for when this condition exists, tightening the upper nut will bring all the pressure to bear at this one point, to which the surface contact between the wire and nuts will be restricted. The contact will then be very poor. When, however, the wire is laid on the lower nut in the manner shown in Fig. 3 (*b*), the bearing surface between the wire and the two nuts will be extended throughout the length of the circle, and the contact will be very much better. Moreover, with the conditions shown in (*a*), the wire is liable to become flattened at *c*, in which case the upper nut will become loosened and the wire will no longer be held firmly.

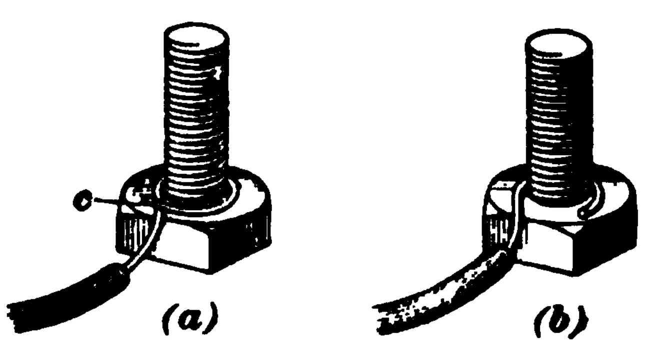


Fig. 3

11. **Cords** for desk stands and other purposes are terminated by the Kellogg Switchboard and Supply Company, as shown in Fig. 4. First, the outer braiding is bound with bare wire, as shown at (*a*); then a sheet metal punching is clamped over the bare wire, as shown at (*b*), thus holding

the braid firmly, so that it, instead of the conductor, will receive all the stress; and, finally, a one-piece cord tip is placed in position and soldered to the punching and binding wire; the finished terminal is shown at (*c*).

12. Transmitter Arms.—Transmitter arms are now usually made hollow, so that two cords concealed within the arm can be used to connect the transmitter with the telephone circuit. This allows the metal of the arm to be entirely insulated from the telephone circuit, so that one is

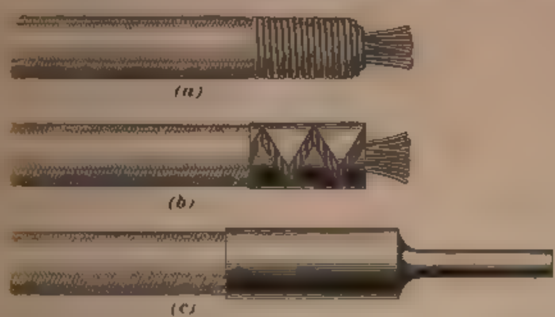


FIG. 4

less liable to obtain a shock by coming in contact with the arm or transmitter.

Transmitter arms are now usually provided with stops that prevent too great a movement above and below the horizontal position. If a granular-carbon transmitter is tilted at too great an angle, the granular carbon will cover only a small portion of the undermost electrode, so that the resistance of the transmitter will prevent the operation of the signal in a central-energy exchange and will interfere also with its action as a transmitter. Trouble with transmitter cords is eliminated also by concealing them within a hollow arm.

13. Mason Arm. The method of making the joint in the Mason transmitter arm is shown in Fig. 5. The hollow arm *a* is held in position without touching the ears *e*, *e* of the supporting plate by means of a pivot pin *c*, on the end *b* of

which is a head, slightly spread so that it cannot be drawn through the ear *e*; on the other end a sleeve *h* slides loosely on the pin and contains a recess for a spring *s* that provides a uniform tension on the pin *c*. The sleeve may be made without a recess, no spring then being used. By means of a thumb nut *d*, the friction between the conical surfaces in the arm *a* and pieces *b*, *h* may be adjusted until it is sufficient to hold the arm in any position, and yet not so great as to prevent its being moved. There are pins *f*, *g* in the sleeve *h* and head *b* to prevent them from turning. Since the arm *a* does not touch the ears *e*, *e*, the surfaces between them require no finishing. No tools are needed for adjustment, and it is claimed that the bearing cones, which may be turned out by automatic machinery from steel, will not wear or work loose, and that the construction is such that it is cheap to manufacture, as well as being a good mechanical joint.

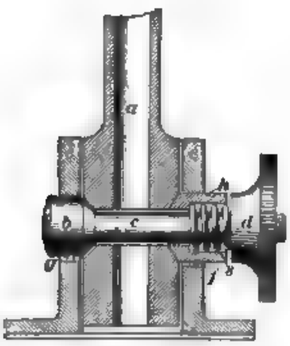


FIG. 5

14. Woodwork.—The woodwork forming telephone cabinets or boxes is usually of oak or walnut. Mahogany, cherry, sycamore, and other varieties of wood, are also occasionally used where it is desired to match the furniture and fittings of the rooms in which they are to be placed. The prime requisite in wood for this purpose is that it shall be thoroughly seasoned and free from knots and checks. The custom hitherto has been, in the ordinary wall instrument, to make the generator box and the box containing the batteries of $\frac{3}{8}$-inch stuff; this thickness, however, is hardly sufficient to withstand the usage to which telephones are frequently put, both in shipment and in actual service, and a far better plan is to use $\frac{1}{2}$-inch wood, which makes a much more substantial and durable construction. The wood, both inside and outside, should be filled with oil, varnish, or shellac, to prevent the absorption of moisture.

15. Battery Box.—In wall sets, the battery is frequently mounted in a separate box placed on the same backboard as the telephone and signaling instruments, and below them. Many designs of battery boxes have been used. A very convenient arrangement for supporting the battery jars is shown in Fig. 6. A shelf of cast iron secured directly to the backboard is provided for the reception of the battery. The wires leading from the apparatus in the local circuit of the instrument are brought through the backboard at a convenient point, as at a, a'. After connecting the wires to the terminals of the battery, the battery box proper is put in place, being held by clips c, c' engaging against similar clips on the battery box. A downward pressure on the box serves to clamp it more tightly, while it may be removed at any time by striking it a blow from beneath. The advantages of this type of box are that all its parts are readily accessible, which is not the case where the box is secured permanently to the backboard, the lid only being removed to allow access to the cells. Inasmuch as the top of the box is nearly always used to a certain extent as a writing desk, the downward pressure on the lid will only serve to clamp it tighter; whereas, with a separate lid, the reverse is frequently true.

FIG. 6

FORMS OF TELEPHONE SETS

WALL SETS

16. As telephone sets are made in many ways, it is not advisable to describe or illustrate here more than one wall and one desk set. A common form of local-battery bridging wall telephone made by the Sumter Telephone Manufacturing Company is shown in Fig. 7. It has two dry cells in the lower compartment for operating the transmitter *T*, which is mounted on the end of a hollow steel arm *d*, having as much of an adjustable up-and-down movement as is advisable. Some cabinets are made large enough to hold either two dry or two Leclanché cells.

The hook switch, which is self-contained, and the induction coil are placed in the upper compartment, in which room is also provided for the bell, which is mounted on the door. Strips of sheet copper *v*, *w*, soldered to the hinges and securely fastened in place, connect the bell, through hinges having spiral springs, to the other part of the bell circuit, while flexible cords are used for extending the primary circuit to and through the cover and the hollow arm *d* to the transmitter. It is no longer considered good practice to use the transmitter arm as one side of the transmitter circuit.

In the middle compartment is mounted a five-bar bridging generator, which, being heavy, is fastened to the woodwork at the bottom, and also by means of a clamping plate located near the top and at the back of the permanent magnets. At *c*, *e* are shown the terminal connections of the generator.

The terminals of the telephone circuit are brought to the line binding posts *A*, *A'*, to which the line wires are to be fastened. Although the proper place for a lightning arrester is somewhere in the circuit outside the telephone instrument, the demand for a lightning arrester on the telephone compels most makers to place one on instruments for the use of private parties and small telephone companies.

The lightning arrester on this telephone consists of two metal pieces *m*, *n*, insulated from each other by the well-seasoned woodwork and from the carbon disk *o* by a disk of mica, about .01 inch thick. On *m* is mounted the line

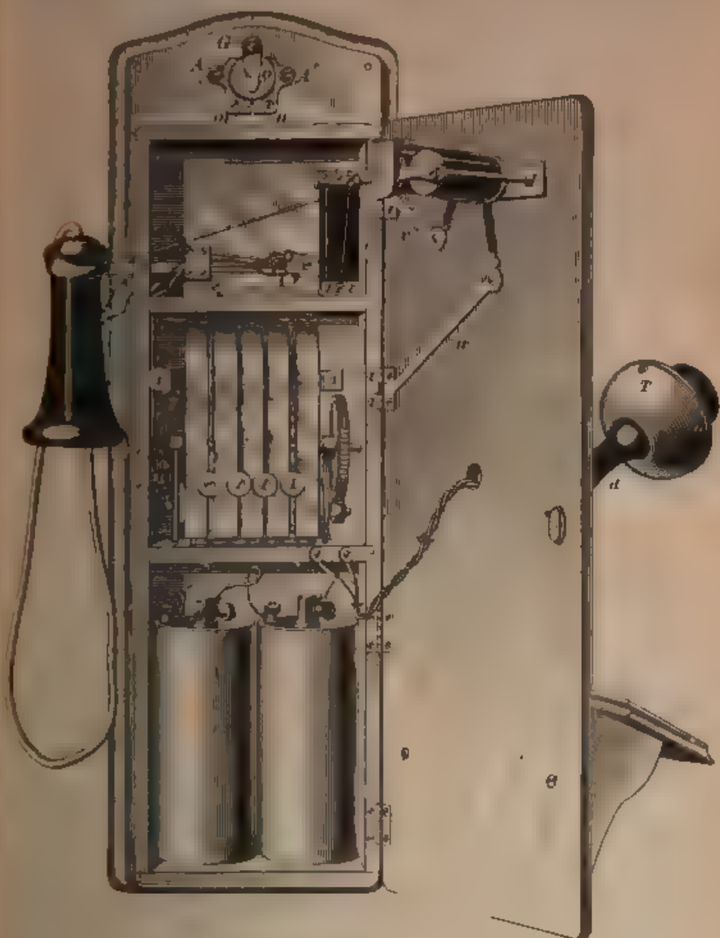


FIG. 7

binding post *A*; on *n*, the line binding post *A'*. The metal piece in contact with *o* is secured in position by, and connected with, the ground binding post *G*, which should be

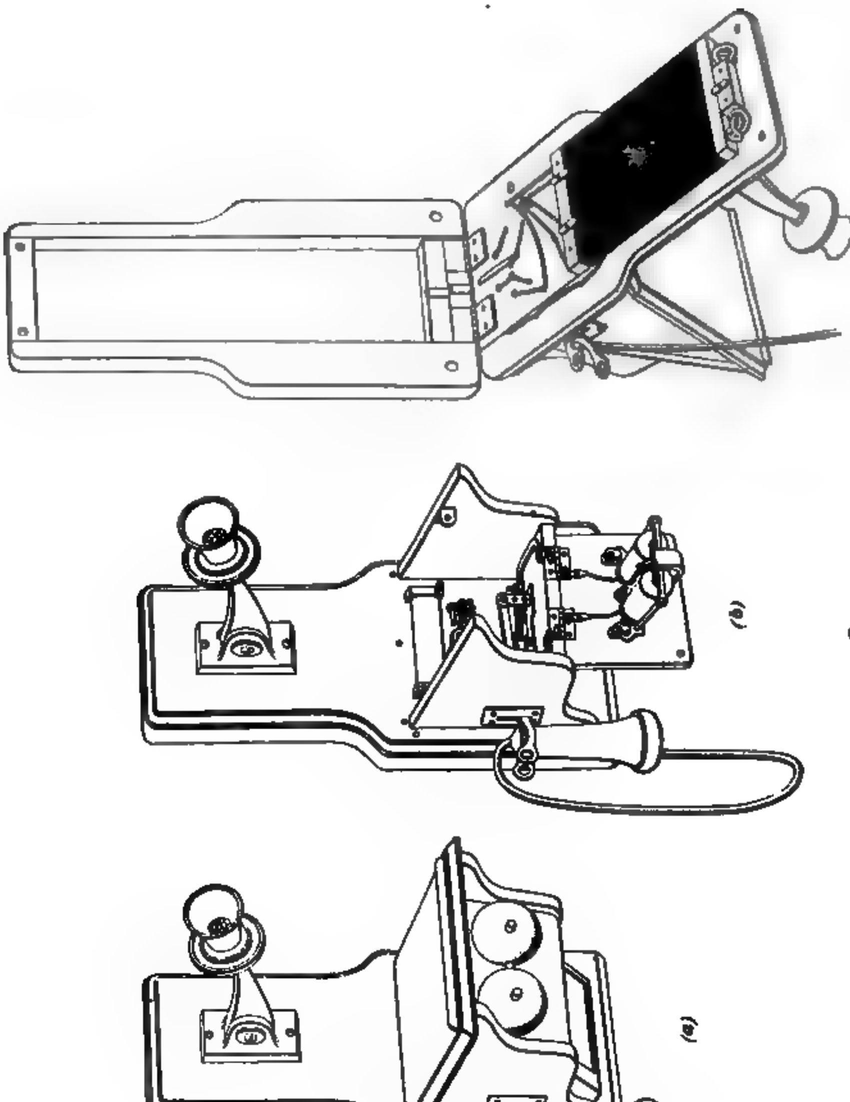


FIG. 8

connected by a wire with a plate or pipes buried in moist ground. A lightning discharge coming in over either line wire jumps from either plate m, n through the narrow gap filled with air or mica to the plate connected to G and thence to the ground.

It is advantageous to have a conspicuous number plate on each telephone, so that, if the telephone number is requested while parties are talking, it can be readily given, thus saving the time required to look it up. Such a number plate is shown on the transmitter case in the Dean desk stand, Fig. 9.

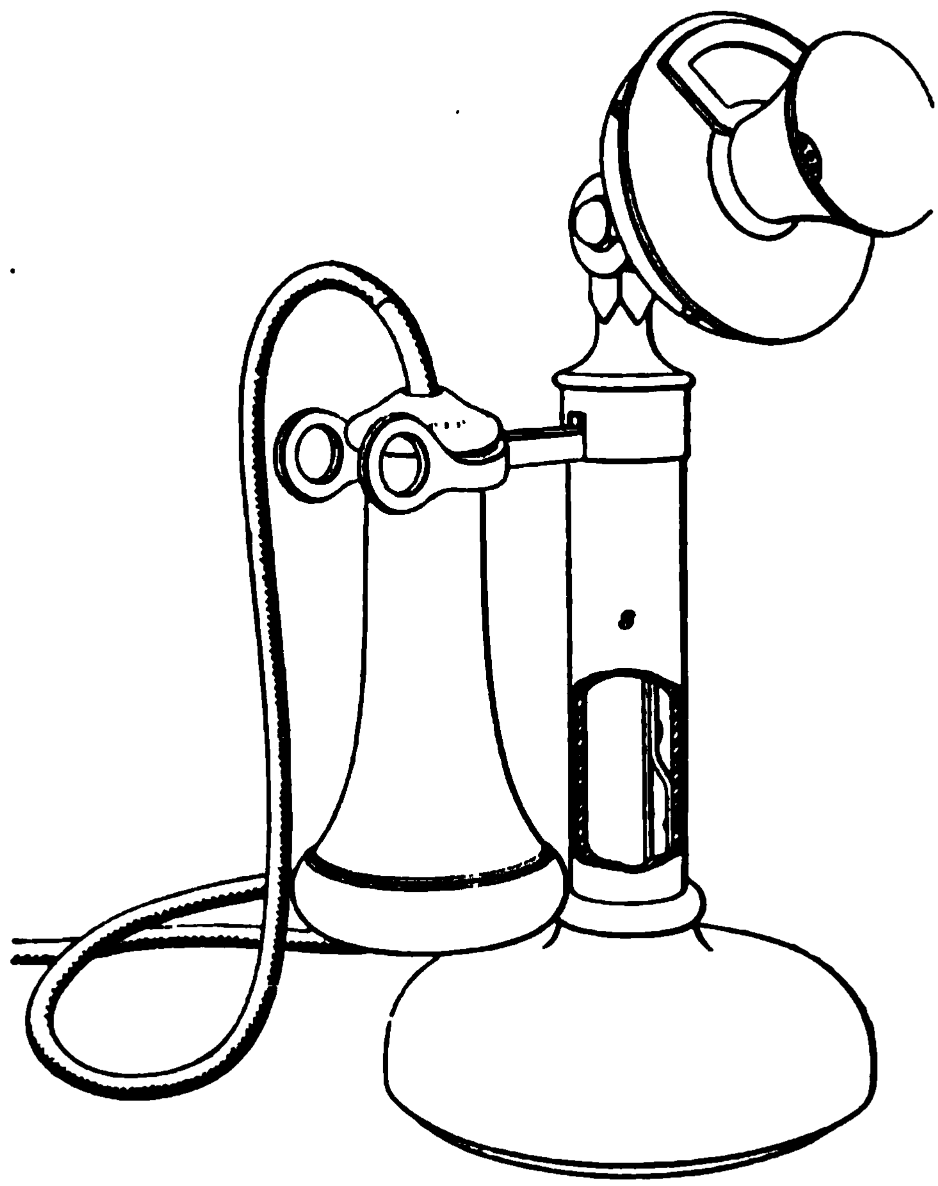


FIG. 9

17. Common-Battery Wall Telephone.—The general appearance of a common-battery wall telephone is well represented by the instrument made by the North Electric Company and shown in Fig. 8 (*a*). At (*b*) and (*c*) the instrument is shown open for inspection, all parts and circuits being readily accessible, and so arranged that any part can be removed without interfering with the other parts of the instrument. The bell and hook switch are self-contained, and the latter has platinum contacts. The condenser *d* and much of the wiring is in a cavity in the backboard.

PORTABLE DESK SETS

18. For business men who wish to be able to use the telephone without leaving their desks, the form of instrument shown in Fig. 9 is very convenient. This set is typical of many. The hook is usually adapted to bring about the same changes in circuits as those already described, but are necessarily somewhat modified in their mechanical form in order to be available for use in this form of instrument. The hook lever usually projects from the side of the standard that supports the transmitter.

In desk sets, the induction coil may be mounted in the base of the standard supporting the transmitter and receiver.

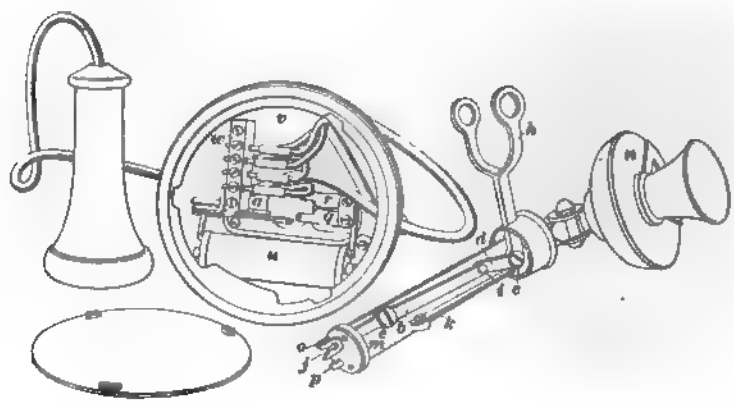


FIG. 10

The generator and ringer, or whatever calling apparatus is used, is mounted on a separate portion of the desk, so as to be out of the way, and yet within the reach, of the user. The connections between the calling apparatus and the talking apparatus are usually made by means of a flexible, silk-covered, conducting cord containing three or four separate conductors. This flexible cord, which of course is entirely separate from the receiver cord, serves merely to make the connections between the calling apparatus and the telephone instruments proper.

19. The **Dean Electric Company's desk stand** is shown in Fig. 9. The steel tubular standard *s* is covered by an insulating composition, or hard rubber shell. This desk stand has the hook switch contact springs mounted within the base, as shown at *a*, Fig. 10, so that the platinum contact points are open for inspection by simply removing the bottom of the base. The motion of the receiver hook *h* is transmitted to the contact springs *a* by an intermediate lever *b*, which is pivoted at *e* to the steel inner frame *m* of the stand. The upper end of lever *b* is forked to embrace a pin *i* in the bell-crank *d* of the hook lever *h*, while the lower end is also forked as shown at *j* to embrace and operate the circuit-changing springs *a*. A main spring *k* attached to the frame *m* engages the bell-crank *d* so as to raise the hook *h* when the receiver is removed.

The top of the steel inner frame *m* carries the transmitter *n*, while the lower end has two insulated contact studs *o*, *p* that are located so as to engage the two flexible springs *r* and *q*, respectively, and carry the transmitter circuit to the base of the stand. This inner frame *m* is arranged to slide into the tubular standard, where it is securely locked by a spring catch (see Fig. 9) attached to the frame; a hole in the spring catch slips over a projection on the inner side of the tubular standard. This construction allows the entire mechanism of the desk stand to be readily exposed for examination without disturbing the wiring or removing any small parts, such as screws, that are liable to become misplaced or lost. The inner frame has a key fitting into a slot in the top of the tube, so as to prevent either from turning and to keep the parts in proper condition relatively to the base.

A novel feature of this desk stand is the removable circuit plate which contains all the talking-circuit apparatus completely wired to form a unit. These units are interchangeable and are arranged for local or common-battery service, the remainder of the desk stand being the same for both circuits.

Fig. 10 shows the arrangement of the circuit-plate apparatus for a common-battery desk stand, which consists of a

coil *u*, receiver and desk-cord terminal block *w*, hook-switch contact springs *a*, and transmitter terminal springs *q*, *r*. These parts are insulated from each other and from the steel mounting plate *v*, the latter being designed to be fastened within the base of the desk stand by means of three screws.

20. Adjustaphone.—In Fig. 11 is shown an adjustable telephone, frequently called the **adjustaphone**. This adjustaphone has a double extension *a b c*, giving a reach of about 27 inches. It is also made with only one extension *a b* and with different mounting bases, so that it may be secured to horizontal, or vertical, surfaces, that is, to flat-top desks or to

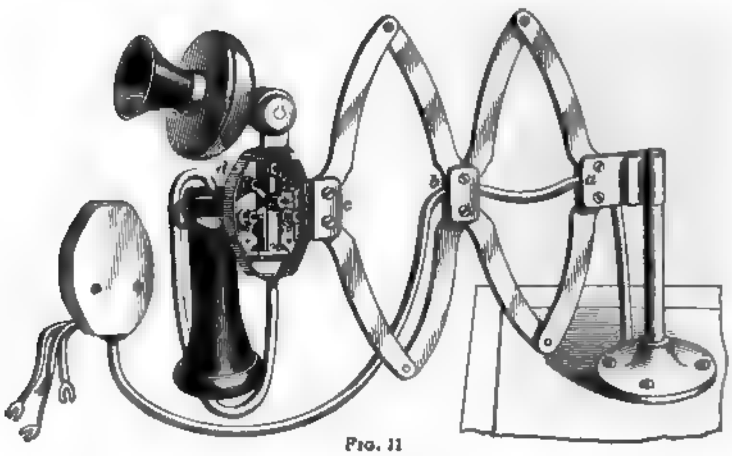


FIG. 11

walls and roll-top desks. The box *d* encloses the hook switch and cord connections, and the transmitter is adjustably secured to it. The lever arms and base are made of steel. The adjustaphone is more convenient in many cases than either wall or desk sets, and, as it cannot be dropped, is subject to less damage than desk stands.

CABINET DESK SETS

21. Still another form of instrument that is convenient for large offices, for telephone booths, and for private residences, is the cabinet desk set, one type of which is shown

in Fig. 12. In this, the transmitter is usually mounted on a gooseneck arm rigidly secured to the top of the desk. The generator, ringer, induction coil, and hook switch are mounted on the top of the desk, but are enclosed, as shown, by a cabinet having a glass front, so that all parts are clearly visible. The generator crank projects from the right-hand side of this cabinet, while the hook switch on which the receiver is hung projects from the left-hand side.

The batteries are mounted within a box just under the desk top, the front board *B* of which box is usually made removable, in order to gain access to the batteries. These desks are very convenient, and may, moreover, be made as ornamental as desired by incorporating in them the finest workmanship and design. The metallic parts of the calling apparatus are usually nickel-plated and highly polished, and when seen through a beveled glass front, present a very attractive appearance.

FIG. 12

SUBSTATION PROTECTING DEVICES

22. Telephone circuits must be protected against lightning, high-potential currents (which may be produced by a cross with electric light or power wires), and sneak currents (which are too small to do instantaneous damage, but which may, if they persist, cause the accumulation of sufficient

heat to damage the apparatus). Any one of these may cause a fire, but only the first two are dangerous to human life. A complete system of protection would comprise a fuse, a heat coil, a carbon lightning arrester, and a grounding device for each line; and during the past, a number of devices, designed to do various parts of this work, have been placed on the market by different manufacturers. The Fire Underwriters' Association requires all protecting devices to be mounted on porcelain or other non-combustible bases.

Telephone protectors may be classified in three divisions: (1) protectors for telephone instruments at the subscriber's station; (2) protectors for switchboards at the exchange office; (3) protectors for cables, ordinarily placed on the poles. Only devices of the first class, which are frequently termed **substation**, or **individual, protectors**, will be considered here.

LIGHTNING ARRESTERS

23. A **lightning arrester** is a device designed to protect apparatus from injury during lightning storms, due to atmospheric electricity, which, when it charges or strikes the line wires, causes a dangerous current to follow them into the apparatus. If unprotected, the coils of the instruments would often be burned out, and any one using the telephone at the time might be injured. The lightning arrester is frequently called a **static** arrester.

The lightning arrester shown in Fig. 13 and made by the Stromberg-Carlson Telephone Manufacturing Company for use on telephone instruments well illustrates this type of protecting device. It consists of three parts insulated from each other; a carbon block *a* is in contact, through the metal piece *h*, with the binding post *T*, which is connected to one line wire; similarly, the carbon block *d* is in contact, through the metal piece *j*, with the binding post *S*, which is connected to the other line wire. The carbon blocks *b*, *c*, which are insulated from the carbon blocks *a*, *d* by thin pieces of mica or oiled silk *e*, *f*, are in contact, through the metal pieces *i*, *i*, with the binding post *G*, which is connected to the ground.

The pieces *i, i* do not touch the carbons *a, d*. The carbons are of such size as to offer a sufficiently large discharge surface between them, and are inserted between stiff springs that keep them under constant pressure and so insure good contact with them. The support at one side of the carbon block extends over the top of the carbons sufficiently to cover the opening between them, thus preventing dust and other particles from collecting at this point. The carbons may be removed without difficulty by simply pushing them upwards from between the springs. The points of the saw-toothed edges on the pieces *h* and *j* are quite close to the grounded piece *i, i*, and are supposed to facilitate the passage of a spark across this part of the air gap. The efficiency of this part of the device,

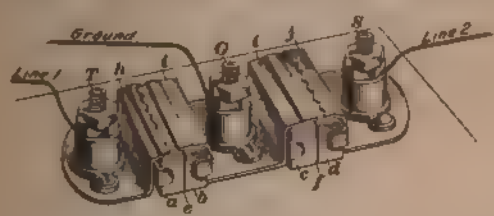


FIG. 13

which resembles an arrester now generally discarded, is doubtful, although its presence is certainly not harmful.

24. Distance Between Carbons.—When devices of this character are used to protect exchange apparatus, the carbons are separated by an insulating material *c, f* .005 inch thick, which will allow a difference of potential of 350 or more volts to break down or puncture the air gap or insulating material between them, thus allowing the discharge coming over either line to pass to the ground instead of through the apparatus, which it is apt to damage. When placed on telephone instruments connected with exchanges, however, they are comparatively inaccessible to the exchange attendants, hence they are provided with a slightly wider air gap than is used on the exchange, probably from .01 to .015 inch represents the best practice in these cases. Thus the exchange arrester, which can be more easily

attended to, will usually operate first, and so prevent the operation of the substation arrester and a trip to repair it.

Mica is probably the best insulating material for this purpose, as it does not carbonize. Where paper is used, it should be renewed after every severe lightning storm. Arresters of this type are extensively used in the United States by both telegraph and telephone companies and are built in a great variety of forms.

25. Action of Lightning Arresters.—The resistance offered by the insulation between the two plates is the same for alternating currents of high or low frequency as it is for steady direct currents. But lightning discharges are usually considered to be oscillatory in character, that is, the current surges back and forth thousands of times per second, and a coil of wire, especially when wound on an iron core, has a very much greater resistance for such a current than for a steady direct one.

The excess resistance that a coil of wire offers to an alternating current over a direct current is due to that property of the coil called its *inductance*. For a given coil and a given intensity of the magnetic flux, the inductance L is constant, but the apparent resistance opposing the current increases rapidly as the number of alternations of the current per second increases; that is, the higher the frequency of alternation, the greater will be the so-called apparent resistance of the coil of wire. To a steady direct current, the resistance of a given circuit is found by Ohm's law to be $R = \frac{E}{I}$. But when E and I are alternating in character, the relation between E and I will have so changed that the quotient $\frac{E}{I}$ will no longer give the same value for the resistance as found above, but will give some other value, which we will call Z. It is a well-recognized fact that for a simple alternating current the value of Z may be found from the following formula:

$$Z = \sqrt{R^2 + (2\pi n L)^2}$$

in which R = the ordinary resistance the circuit will offer to a steady direct current;
L = inductance of circuit;
π = 3.1416;
n = frequency.

The frequency is the number of complete cycles per second, or twice the number of alternations per second. The quantity $\sqrt{R^2 + (2\pi n L)^2}$ is called the *impedance* of the circuit, whose ohmic resistance is R and whose inductance is L. The value of this expression evidently increases if any of the quantities R, n, or L increases, and decreases if any of them decreases. For a lightning discharge, n is very large, but for an air gap, even if the air space is replaced with mica or any other insulating material, L is zero. Consequently, the impedance of the air gap is always about equal to R, no matter how large n is, because $2\pi n L$ is zero when L is zero. Therefore, $\sqrt{R^2 + (2\pi n L)^2} = R$ when $L = 0$. But for the coils on the instrument, L has an appreciable value; it may amount to several henrys or more. Consequently, when n has a very large value and L is not too small, the value of $\sqrt{R^2 + (2\pi n L)^2}$ will be very large. As a matter of fact, n is large enough in lightning discharges to make the value of R^2 insignificant compared to $(2\pi n L)^2$. Therefore, for a lightning discharge, the impedance of the air gap remains equal to R, because L is zero, as already stated; but the impedance of the coils of wire in the instrument increases so much in value that the air gap becomes, for a lightning discharge, a path of low resistance in comparison with it, and since a current will always take the easiest path, the discharge will jump the air gap in its effort to reach the ground, in preference to going through the coils on the instruments.

If the lightning discharge were compelled to go through the coils to earth, it would invariably burn out the fine wire in the coils and also ground the coil to the iron core. It would thus ruin the coil, and, in its effort to reach the ground, would probably do much damage. Direct or low-frequency currents under 350 volts will not jump an air gap of .005 inch, because the difference of potential

is not great enough, and because to them the coils offer an easier path.

26. The **ground wire** for lightning arresters should take the shortest and most direct route from the arrester to the ground. It should also have as few bends and turns as possible, as in the case of violent discharges the lightning is very apt to take short cuts through combustible materials and thereby do considerable damage. Never use a spiral of wire, called a pig tail, between the ground side or terminal of an arrester and the ground. Experiment seems to show that iron wires will conduct lightning as well as copper wires, and that is it quite immaterial whether or not the connection of the ground wires is soldered, provided that no air gaps of great length occur at any of the connections. It is obvious that, if lightning will jump over air spaces, a poor joint will offer but little opposition to such a discharge. Nevertheless, it would seem advisable to make all the joints good, and thus offer as good a path as possible to the ground.

Carbon-block lightning arresters should be taken apart, cleaned by wiping or blowing away all carbon dust, and carefully put back in proper order after lightning storms, especially after severe ones. This should be done by all subscribers and telephone owners in country and thinly populated districts, where bare line wires are very much exposed, but it is rarely necessary in a city.

27. Carbon Blocks.—The carbon blocks used in static arresters at exchanges, substations, and elsewhere are usuallv of the shape shown at *H*, *H'*, Fig. 14. The mica is cut to the form shown at *e*, or has holes punched through it, so as to more readily allow the current to jump across the air space thus provided. When cut as shown at *e*, the cut-out portion should be placed downwards, if possible, to better allow any carbon dust that may be formed to fall out.

Sometimes a drop of fusible metal, or a small lead shot held in place by wax, is so placed in a depression *h* that normally it will not touch the other block. This block *H'* is then placed above block *H*, or in such position that the

fusible metal or shot, if free to fall, will connect both blocks and reduce the air-gap resistance, practically, to zero. If a current caused by a high potential, 350 volts or over, comes in over the line, it will pass to the carbon block H', jump across the air gap to the block H, and pass to the ground. If the discharge is of sufficient duration, the fusible metal or wax in the cavity in the block H' will be melted, and connect the two carbon blocks together, thus completely grounding the line wire. The idea was formerly held that a heat coil, which will be presently described, would not operate without this more complete grounding of the line.

FIG. 14

28. Toll-Line Arrester. In Fig. 15 is shown the individual lightning arrester made especially for use on long rural, farmers', and toll lines, for protecting which it has proved very successful. The binding post G, which is in contact with the middle carbon, is to be grounded; one line wire is connected to A and one instrument lead to B; the

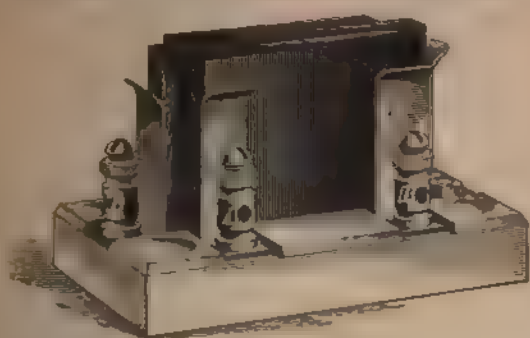


FIG. 15

other line wire and instrument lead are connected to similar binding posts on the other side.

The outside carbons are insulated from the middle carbon by thin sheets of mica, and the three blocks are firmly pressed together by the springs c, d, which are wide and strong enough

to make good contact with the outside carbons. Normally, the telephone currents pass through the outer carbon blocks only, but lightning discharges readily jump to the inner carbon and pass to the ground. The desirable feature of this arrester is the large surface between the line and the ground carbon plates.

29. The Mason Multidischarge Arrester.—The distinctive feature of this arrester, which is made by the Sumter Telephone Manufacturing Company, consists, as shown in Fig. 16, of coils of bare wire *s*, *s* wound around

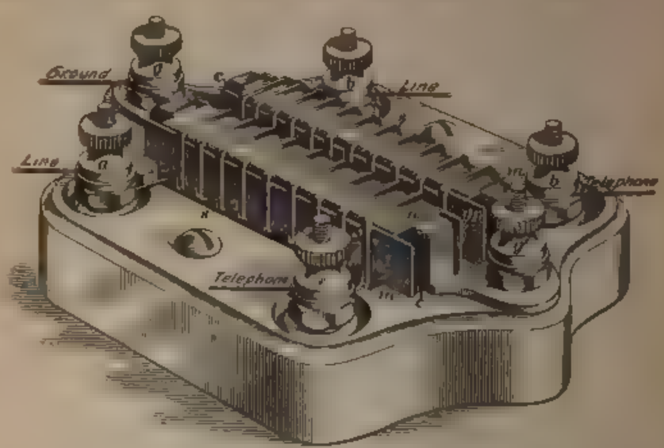


FIG. 16

rectangular carbon blocks *c*, *c*, from which the turns are insulated by mica *m*, *m*, cut away at the edges, thus exposing an air gap along each edge between the conductor and the carbons, which are connected to posts *g*, *g'*, either of which may be connected to the ground. There is one coil in circuit with each side of the line and the telephone instrument. To the very high frequency lightning discharges, the coils present a high impedance, or choking effect, that tends to force the discharges across the many air gaps between the spiral conductor and the grounded carbons. The low resistance and few turns in each coil cause them to possess no appreciable impedance for the signaling or talking

currents. The connections for a complete metallic-circuit telephone are indicated in the figure. For a ground-return circuit, join *a* to *g*, *b* to the one line, and, as here indicated, *g* to ground and *c*, *b* to the telephone instrument.

FUSES

30. Lightning arresters protect apparatus by temporarily or permanently grounding the line wire; and in the case of a lightning discharge, which persists for only a brief time, no other protection is necessary. However, a high-potential current due to a cross between telephone and high potential line wires is apt to persist after the telephone line is grounded at the lightning arrester, and thus cause a very large current to flow over the conductor so grounded, which is very apt to damage the conductor, especially if it is in a cable. It is, therefore, desirable to provide means for opening the circuit after it has been grounded, in case a dangerously large current is produced. This is accomplished, in a simple manner, by the use of a *fuse wire* of limited carrying capacity. The fuse is sometimes called the *strong-current protector*, because it protects the conductors against relatively large currents, that is, currents of 5 or more amperes. If it were not for the fuse, the arc produced in the lightning arrester, due to a cross with a high-potential wire, would persist and probably destroy the arrester, and perhaps all other apparatus there located, and even set fire to the building. The fuse should, therefore, be placed between the lightning arrester and the open line wire where the cross may occur; it should not be placed between the lightning arrester and the telephone instrument or cable conductor that it is used to protect.

31. Fuses are pieces of soft wire that melt and open the line circuit, if the current exceeds a certain value. For telephone circuits, the capacity of a fuse depends on its location. In order to reduce expenses of maintenance to a minimum, the fuse at the exchange should be of smaller capacity than that at the subscriber's station or elsewhere in the circuit. The exchange fuse, which is the easier replaced,

will usually then blow first, and probably prevent the blowing of any fuse outside the exchange. The larger the current abôve the limiting value or capacity of the fuse, the quicker it will melt. When a simple fuse melts, it merely opens the line circuit and does not usually ground it; consequently, a fuse cannot be considered as a protection against lightning, though it is a fairly satisfactory protection against crosses.

Enclosed fuses are now used extensively by both telegraph and telephone companies to protect the wires in cables and apparatus from excessive currents caused by crosses on open overhead wires. The fuse shown in Fig. 17 consists of an enameled wood, paper, or fiber tube, about 4 inches long and ½ inch in diameter, with metal terminals secured to the ends. The tube prevents the scattering of the fuse that is inside, when it melts, and, being almost air-tight, protects the fuse from currents of air, and thus causes it to operate more

FIG. 17

uniformly. The fuse is made long, so that at least 2,000 volts at its terminals will be required before an arc can be maintained between them at, or after, the melting of the fuse Excellent enclosed fuses, mounted on porcelain bases and made by the D and W Fuse Company, are now used by telegraph and telephone companies.

COMBINED STATIC AND FUSIBLE ARRESTERS

32. Cook Arrester and Fuse.—Fig. 18 shows a combined static and fusible arrester, or, as it is frequently termed, a fuse and open space cut-out (lightning arrester), made by Frank B. Cook. The fuse is enclosed in a substantial wooden cylinder, at each end of which is attached a terminal so contrived that it may be sprung into place between German-silver clips. A fuse wire of any desired capacity, preferably

from 5 to 7 amperes, is strung through the center of the cylinder and attached to the terminals; while a hole drilled crosswise in the center of the cylinder allows the escape of the hot air and volatilized metal when the fuse blows. The clips into which the fuse is inserted are arranged to hold a pair of carbon plates, between which a thin sheet of mica, or other non-combustible material, perforated with three holes, is placed. This air gap can be adjusted by varying the thickness of the mica for any desired potential.

The combination of static arresters and long fuses forms a very efficient protection for the telephone instrument, the premises, and for the line conductor. Carbon blocks should

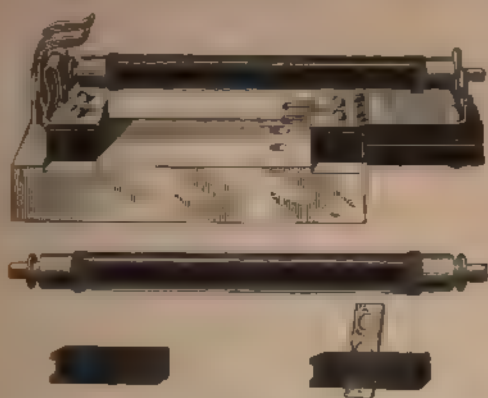


FIG. 18

never be used without a long fuse on the line side, otherwise a dangerous fire may result. An exception may sometimes be made on rural lines, where there are no electric light, power, or other circuits in the neighborhood.

33. A form of arrester largely used among independent telephone companies consists of a small fuse block on which is mounted a very fine fuse about 2 inches in length. In order to prevent breakage of the fuse wire itself, it is usually mounted on a thin strip of mica, being secured thereto by shellac. The mica strip is provided with metal terminals, which may be slid between the clips of the fuse block. The fuses used are generally rated at $\frac{1}{8}$, $\frac{1}{4}$, or $\frac{1}{2}$ ampere; these

ratings are not at all reliable, however, and it is not an unusual thing to find a fuse whose rated capacity is $\frac{1}{8}$ ampere carry over 1 ampere. These fuses will in many cases protect telephone apparatus from the damaging effects of small currents. They cannot, however, be depended on to afford protection from either lightning or crosses with high-potential light or power circuits. They are not as reliable as heat coils, which will be considered presently, nor should they be used for the same purpose as the longer enclosed fuses.

34. Since short fuses of the character just described can be depended on for protection only against small currents and low-potential circuits, they are placed between the lightning arrester and the telephone instrument.

In Fig. 19 is shown an arrester designed to give protection from both lightning and low-tension currents. The fuses are

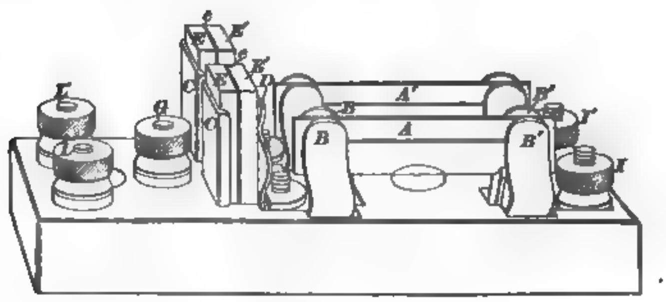


FIG. 19

mounted on mica strips A, A' that are held in place between the metallic clips B, B'. C, C' are upright strips of brass permanently connected with the binding post G, which is grounded. Between the clip C and the upright spring D, which is in metallic connection with the fuse clips B and also with the binding post L, are placed two carbon blocks E, E', held apart by a thin strip of mica e. This strip of mica often has a small piece cut out at its center, in order to allow the arc between the two carbons to start a little easier. L, L' are the line binding posts, while I, I' are the posts connected with the instrument to be protected. The normal circuit through this arrester is from

the post L to the clips B, B, through the fuse wire to the clips B', B', to the binding post I. A current of sufficient strength will melt the fuse on A and open the circuit. If the current is of sufficiently high voltage, it will jump across the small gap between the two carbon blocks E, E', formed by the mica strip c, and pass to the plate C, thence through the binding post G to ground. The carbon blocks can be easily and quickly slipped out, cleaned or repaired, and returned to their places, or new ones substituted.

SNEAK-CURRENT PROTECTORS

35. Sneak currents may be caused by the telephone line coming in contact with a low-potential line, such as an incandescent-light or telegraph line, or with a high-potential line through a high resistance. In central-energy systems, another cause of sneak currents is due to the grounding of one of the telephone wires or the crossing of two telephone wires, in which cases the current produced by the common battery alone may be sufficient to cause ultimate damage to the apparatus. However, such damage would be confined usually to apparatus at the exchange.

Protection against such small currents may be obtained by the use of fuse wire of very small current-carrying capacity, but with the small fuses required for this purpose, currents of a certain strength cannot always be depended on to melt the fuses and open the circuits. On account of their small size, such fuses are, moreover, very frail and subject to mechanical injury. The device called a **heat, or sneak-current, coil** will, however, afford this protection.

36. Sterling Heat Coil.—One of the latest heat, or sneak-current, coils, made by the Sterling Electric Company, is shown in Fig. 20 (a) in its normal condition before operating, and in Fig. 20 (b) after it has operated. It consists of three metal pieces c, d, e, two pieces m, n of insulating material, and a coil of German-silver wire u. One end of the coil is connected to the end piece d, and the other end to a hollow sleeve e. Normally, the end piece c is secured to the

sleeve *e* by a readily fusible solder sweated between the two surfaces. The heat produced in the coil by .3 ampere in 25 seconds, or by .22 ampere in 55 seconds, is sufficient to soften the solder so that springs engaging the end pieces *c*, *d* can readily pull *c* out of *e*, as shown at (*b*), thus producing a

Fig. 20

wide air gap (between *c*, *e*) in the circuit and usually grounding one of the springs. The coil will carry .15 ampere for at least 5 minutes without operating.

37. Combined Protectors. Protecting devices used at each telephone usually consist of a carbon static arrester, and either a fuse or a sneak coil; sometimes static arresters, fuses, and heat coils are all used. One of the carbons is, of course, grounded, and a fuse or sneak coil is connected in each line. Tubular fuses are preferable, but fuses stretched on a fiber strip are sometimes used. Where heat coils and lightning arresters are used at substations, the heat coil should be on the telephone side of the arrester; if a long fuse is also used, it should be on the line side of the arrester.

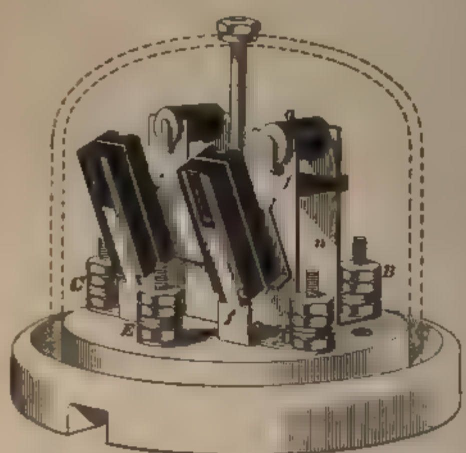


Fig. 21

38. Sterling Sneak-Current and Lightning Protector.—Fig. 21 illustrates the combined sneak-current and

lightning protector made by the Sterling Electric Company, for use on individual telephones. It is double-pole, i. e., it protects the apparatus from dangerous currents entering over either line wire One line is connected to the binding post *A*, the other to *C*. From *B* a wire goes to the telephone; the binding post from which the other wire goes to the telephone is not in view. The binding post *E*, to which the piece *e* is fastened, is connected by wire with the ground.

There are two pairs of carbon blocks, one pair in each line circuit. One block of each pair is separated and insulated from the other block by a piece of silk ribbon or braid. Embedded in a depression in the surface of one carbon of each pair, next to the piece of silk, is a small metal or carbon ball, held in place by an easily fusible wax. A sufficiently high potential to arc between the carbons will melt the wax and permanently ground the line; that is, the ball will fall by gravity and connect the two carbons together.

From the binding post *A*, the circuit continues through spring *f*, heat coil *a*, spring *n*, to binding post *B*. When a heat coil of this kind operates, it must be removed and a new or repaired one inserted in its place. The cover to this protector is made of strong glass.

39. It is necessary to have a heat coil proportioned to the apparatus to be protected. A heat coil that will protect a series-bell or coil wound to 80 ohms may not protect a coil wound to 1,000 ohms. The average heat coil, wound to a resistance of 25 ohms, will operate on .2 ampere in about 40 seconds, and will stand .15 ampere indefinitely. This heat coil will not protect the average coil wound to 1,000 ohms, for a current of .15 ampere will soon damage the coil. To protect the higher wound coils, a more sensitive heat coil must be used. One wound to 40 or 50 ohms would probably do, but a heat coil of such high resistance should not be placed in the talking circuit of a central-energy telephone. Moreover, in central-energy systems, it is necessary to reduce the resistance of the heat coil, so that the current used for the transmitter and for signaling will not operate

the heat coils. It is necessary in some cases to use a heat coil that will carry over .333 ampere indefinitely. A heat coil having a resistance of 3.6 ohms is used in some of the Bell Company's central-energy systems. It operates on .5 ampere in 240 seconds and must carry .35 ampere for 3 hours. A short circuit on a line in a Bell central-energy system will produce, at times, about .333 ampere, and it is not desirable that this current should operate the heat coil even at the exchange. For this reason, it is necessary so to design the apparatus in such a system that it will stand the current that the heat coil will stand. All heat coils should be wound non-inductively.

40. Danger of Sneak Currents.—The peculiar danger in sneak currrents is that they do not make themselves evident to the senses at once, the first indication of their presence being the smoldering of a coil in the switchboard or telephone, caused by the long continued flowing of the current. There are very few coils used in telephone work that will not stand .333 ampere for a short time, but the flow of such a current for a long time might generate enough heat to char the insulation and spoil the coil. The heat coils form the most effective prevention for currents of this character. By varying the length of the German-silver wire used in their construction, they may be made to have almost any degree of sensitiveness desired. They are often constructed so as to melt the solder when a current of .2 ampere flows through the coil for 25 seconds.

The use of heat coils to protect exchange apparatus is universally advocated, but the addition of a heat coil to the protective device at a subscriber's station is not considered necessary by most telephone engineers, because the cost of the telephones burned out would be much less than the cost of continually replacing heat coils at the subscribers' stations. The use of heat coils to protect switchboard devices will be considered elsewhere.

41. Heat-Coil Solder.—A solder, suitable for use in heat coils, that will melt at about 160° F., may be made by

mixing together one part of block tin, one part of cadmium, two parts of lead, and four parts of bismuth.

Another fusible solder that melts at 160° F. and is said to give perfect satisfaction is made of four parts of tin, two parts of lead, seven parts of bismuth, two parts of cadmium. In making the alloy, care should be taken to prevent the oxidizing of the lead and bismuth, both of which oxidize readily and hence tend to change the proportions.

SELF-SOLDERING HEAT COILS

42. Cook Self-Soldering Heat Coils. Formerly, all heat coils were destroyed when they operated, or at least they required repairing, which was more or less difficult and expensive. Several companies are now manufacturing so called **self-soldering heat coils**, or **self-soldering cartridges**. After they operate they automatically resolder themselves as they cool, and to restore the circuit to its normal condition, it is only necessary to push back the line spring, or to turn the heat coil upside down or end for end.

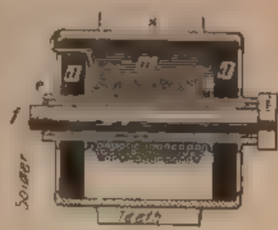


FIG. 22

The self-soldering heat coil made by Frank B. Cook is shown in Fig. 22. It consists of a toothed metal shell *s* that laps over the insulating pieces *d*, *d*, thus completely enclosing the coil *w* of silk-covered German-silver wire that is wound on a small brass spool *e*. These parts are held firmly and permanently together. The brass spool *e* is soldered to a stationary pin *f i* by a solder that melts at a low temperature. One end of the winding is soldered to the brass spool *e*, the other end to the metal shell *s*.

43. The heat coil is mounted in the protector shown in Fig. 23 in such a manner that the pin is held rigidly from turning by the flattened end *i*, while a strong spring *h* engages the teeth on the outside of the shell and tends to rotate the brass spool on the pin, which the solder normally prevents.

However, an abnormally large current passing through the winding of fine wire melts the solder, thus allowing the body of the coil to turn on the pin. This releases the circuit-controlling spring and opens the circuit through the heat coil. The solder cooling again secures the body of the heat coil to the pin. The circuit-controlling spring can then be reset in position, engaging the teeth.

The advantages claimed for this coil are that the solder is so thoroughly protected from atmospheric exposure that it cannot corrode, thus insuring a resoldering of the coil after each operation; that the heat-producing coil is concentrated around the fusible solder, thus insuring quick and uniform operation; that the winding, spool, and all vital parts of the

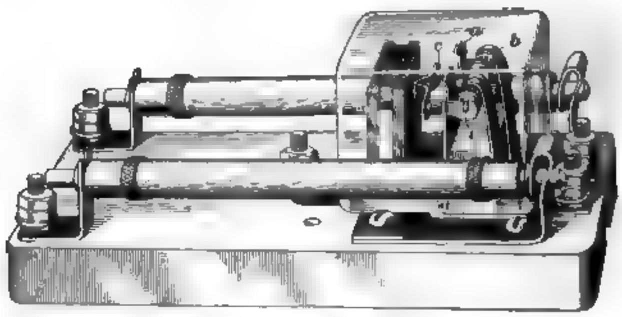


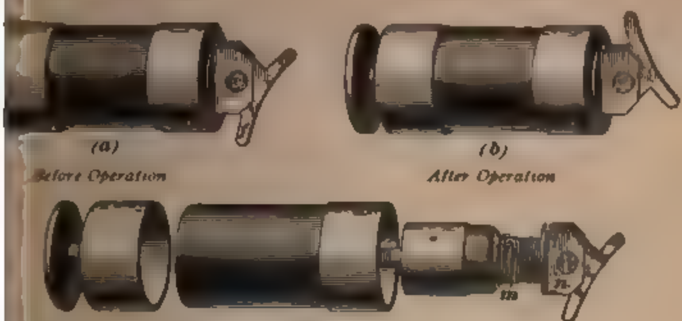
Fig. 23

coil being enclosed, it is impossible for any heat to be lost; and that a variation in outside temperature or air drafts will not affect the operation. It is further claimed that when the coil operates, it turns on the pin through only a small arc of a circle, allowing the solder to give or stretch slightly, like gum, without actually breaking the solder connections; this insures quick and permanent resoldering. The low fusing point of the solder used insures its melting before the winding could become hot enough to be injured.

44. Cook's Lightning, Fuse, and Heat-Coil Protector.—In Fig. 23 is shown the Cook type 12-A subscriber's station protector. It consists of long enclosed fuses, carbon lightning arresters, and self-soldering heat

The enclosed fuses are held between springs so ...ed that they may be readily inserted in place, or ...ed, without the use of any screws or nuts. The car... ...nd heat coils are protected by a stout glass cover that ... easily removed. When the heat coil operates, the ...s *a*, *b* separate, and *a* comes in contact with the grounded ... To reset the heat coil, it is only necessary to push ...ring *b* until it catches hold of a tooth on the surface of ...at coil.

... **American Electric Fuse Company's Self-...ring Heat Cartridges.**—The American Electric ... Company make several forms of self-soldering heat ...r cartridges, as they call them, one of which is shown ... 24; *f* is a trigger that can move about the pivot *e* from



(a) ...efore Operation

(b) After Operation

(c) Self Soldering Cartridge Dissected

FIG. 24

...sition shown in (*a*) to that shown in (*b*). It is nor-... held in the position shown in (*a*) by a solder placed ...d the pivot *e* that melts at a low temperature. At (*c*) is ... the various parts of the cartridge. When an abnor-... large current passes through the German-silver ..., which may have any desired resistance, in some ... about 8 ohms, the piece *n* becomes heated and the ... fusible solder, which normally prevents the move-... of the trigger *f*, softens and allows the spring pressing ...right against the lower part of *f* to move the trigger ...e position shown in (*b*), thereby allowing the spring

to fly out and ground the circuit. After the current has stopped flowing, the solder solidifies and holds the trigger permanently in the position shown in (*b*). To restore the circuit to its normal condition, it is only necessary to push in the line spring and turn the cartridge upside down.

46. In Fig. 25 is shown the self-soldering star-wheel type of cartridge made by the same company. This cartridge operates in much the same manner as the trigger cartridge. Heat developed in the heat coil by an abnormally large current softens the solder, which normally holds the star wheel *o* in position, and allows it to revolve about the axis *e*, thereby allowing the line spring to fly out. When the current stops, the solder solidifies and holds the star wheel in position, and it is only necessary to push in the line spring to restore the circuit to its normal condition, as any tooth of the star wheel that happens to project downwards will hold the line spring in position.

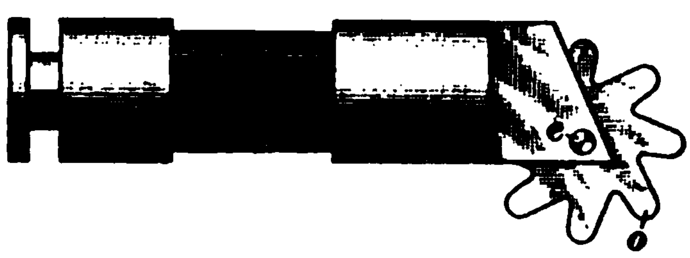


FIG. 25

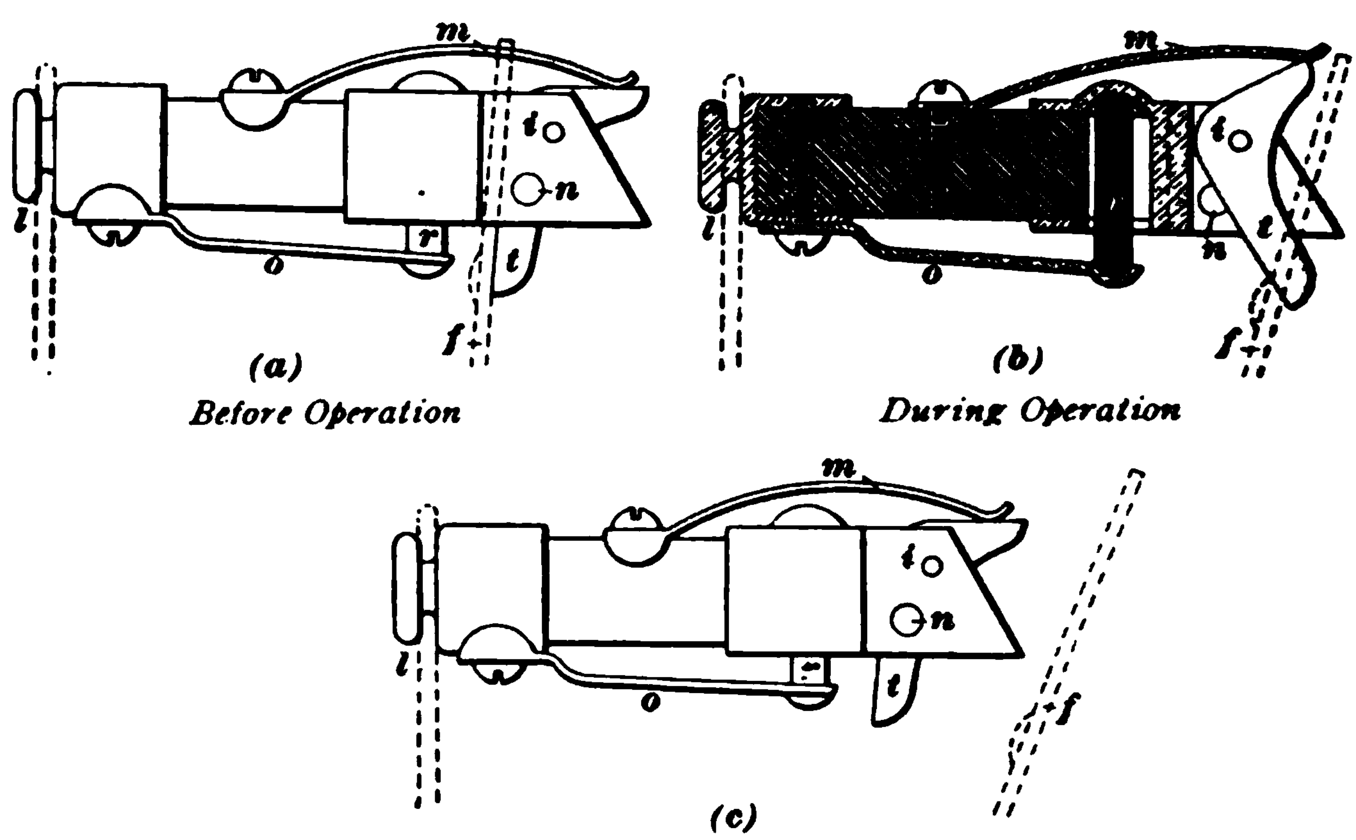


FIG. 26

47. Self-Soldering Graphite Cartridge.—In Fig. 26 is shown the self-soldering graphite cartridge made by the

American Electric Fuse Company. At (*a*) is shown the position before operation; at (*b*), a section of the entire cartridge during operation; and at (*c*), after operation. A current entering at *l* passes through contact spring *o*, graphite resistance rod *r*, trigger *t*, to spring *f*. When the current is excessive, the graphite rod *r* becomes heated enough to soften a fusible alloy placed in holes *n*, thus allowing spring *f* to tip the trigger *t*, which is pivoted at *i* into the position shown at (*b*), which will allow the spring *f*

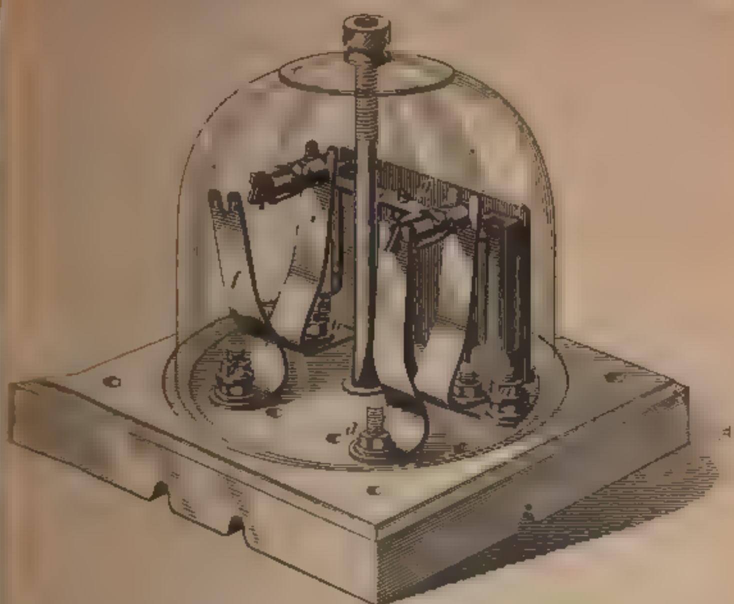


FIG. 27

to pass to position shown in (*c*). The spring *m*, acting before the fusible solder can cool and harden, returns trigger *t* to its normal position, as shown at (*c*). The hardening of the solder then holds the trigger in this position, and the cartridge is again ready for use.

48. One form of individual protector made by the American Electric Fuse Company is shown in Fig. 27. It is a combined static and heat-coil protector, using the

heat coil just described. The line wires are joined to a, b, the telephone leads to c, d, the cross-piece e and plate g are both in contact with a binding post in the rear of g that is to be connected to ground. When the heat coil operates, f is released and i comes in contact with the grounded strip e.

49. The **D and W combination cut-out,** as the D and

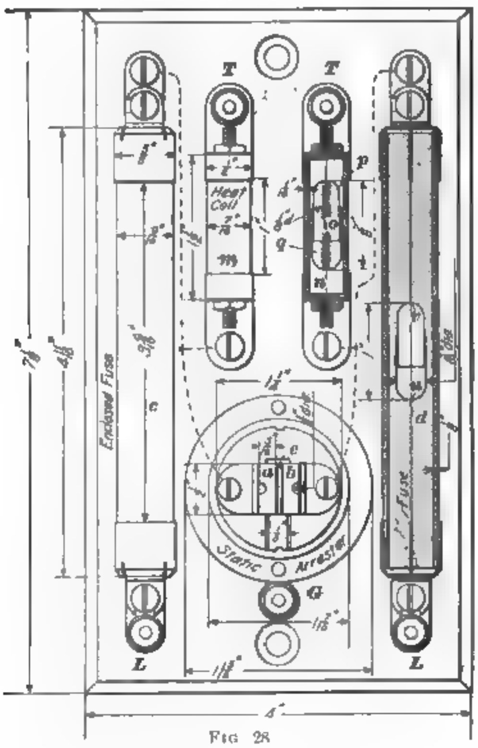


FIG. 28

W Fuse Company call their combined static, fuse, and heat-coil protector, is shown in Fig. 28. The connections indicated by dotted lines are made under the porcelain base on which all parts are mounted. L, L' are the line, T, T' the instrument, and G the ground binding posts. The fuses are enclosed in long fiber tubes c, d, at the center of which they pass through

capsules made of hardened gelatine, one half of a capsule slipping tightly inside the other half of the same capsule, while the holes *u*, *v* through which the fuse passes are sealed with wax. The rest of the tube is filled with gypsum, which will not burn when the fuse blows. This fuse is said to blow promptly without producing any flame or discharge whatever, and to operate satisfactorily on a 3,000-volt short circuit. After the fuses have blown, the tubes must be returned to the maker for the insertion of new fuses.

50. The lightning arrester is of the carbon-plate type, consisting of two carbon blocks *a*, *b*, one connected to the terminal of each fuse, and separated from the center grounded plate *c* by mica, or by an insulating waterproof film, whichever may be preferred. With the mica, an air gap of .008 inch is provided; whereas with the film, but .0025 inch separates the carbon from the ground plate. The brass plate *c* is connected by a piece of sheet brass ⅜ inch wide with the ground binding post *G*.

The arrester is enclosed in a metallic casing, which prevents the accumulation of dust, which has frequently been known to cause trouble, and also guards against any risk from the ignition of lint or flying particles during the instant when a discharge occurs across the plates. The makers claim that the film possesses the property of automatically grounding the device, when the circuit becomes crossed with a high-tension line, in such a manner that only a small current can pass to earth. Though this current may be too small to melt the fuse, it may nevertheless be sufficiently great to cause disturbance and trouble on the line. Under such circumstances, the circuit is automatically grounded, which is desirable, by the rapid carbonization of the film. As soon as the line is cleared, the film is easily and quickly replaced. This, the makers claim, is a decided advantage over the air-gap arrester provided with a mica separator, since a small discharge might continue across the air gap for many hours, interfering with the satisfactory operation of the line, and yet be too small to cause the fuse to operate.

The carbon arrester needs but little attention, and then only to free it from carbon particles that may accumulate within the air gap when mica is used, or to renew the films with the other type.

51. The heat, or sneak-current, coils *m*, *n* each consist of a very small, close-wound coil of bare wire made in two parts *p*, *q*, which are under tension with reference to one another, these being soldered together at *o* by a solder having a very low melting point. The coil is enclosed in a capsule of hardened gelatine, and forms an efficient protecting device against small currents. The sneak-current arresters are built to operate on from .1 to .5 ampere in 15 seconds, those working at .2 or .3 ampere being recommended for telephone service. For fire-alarm service, a .5 ampere coil is recommended. Since trouble from a slight leakage current is more common than from absolute crosses, the sneak coil is made to operate when such currents are diverted through the instrument, the coil being easily renewed and replaced. Tools can be obtained for repairing the sneak-current coils.

A current larger than the capacity of the fuse will melt it within the practically air-tight capsule *u*, *v*. A sneak current will soften the solder at *o*, by the heat produced within the practically air-tight capsule by the spirals of bare wire *p*, *q*, in a given length of time, and allow the tension of the spirals to pull them apart, and thus open the circuit at *o*.

TROUBLES WITH TELEPHONE INSTRUMENTS

SOME COMMON FAULTS AND THEIR REMEDIES

52. In telephones, as in all other systems employing electrical connections, certain defects, called **faults**, will from time to time develop, however well the apparatus may have been constructed and erected. The most common troubles are due generally to one of three causes: First, loose or dirty connections at the binding posts on the instrument, batteries, or protecting devices, or in joints in the

line wire; second, in exhausted, poor, or weak batteries; third, crossed, open, or grounded wires. These troubles, of course, do not include those arising from inferior or defective instruments, which are impossible to enumerate on account of the large number of makes of instruments now in use. In the case of a defective instrument, the best thing to do is to return it to the dealer or workshop for repairs. If any trouble or poor service is noticed on a telephone line, look first for badly constructed joints, loose connections at binding posts, dirty or corroded contacts and connections, and defective batteries. If the connections are dirty, corroded, or greasy, scrape the wires and clean out the binding posts; then screw the wires firmly in place. If the telephone does not work properly then, examine the batteries and see whether they are run down, or if the zincs are eaten away. With wet batteries, it may be that the water has evaporated; in dry batteries, the zinc may be eaten through, or the batteries may be otherwise defective. The simplest way to test the battery is to try a new battery, and see if it will make the telephone work properly; if it does, the trouble was with the old battery. If the trouble is present after changing the battery, examine the line connections and the line outside; if any loose connections are found, correct them at once. When inspecting the line outside, see that it does not touch anything except the insulators, and that it is neither crossed nor broken. On grounded lines, examine the ground connection the first thing, and see if it is in good condition; and if a plate is used, see that it is buried deep enough to be always in moist ground and below the frost line.

If any of the coils in the instrument have been damaged by lightning, the smell of the charred insulation can frequently be detected when the door of the telephone is opened. If this is the trouble, the only thing to do is to replace the coil that has been burned out. One thing that should be carefully avoided is the placing of nails, screws, screwdrivers, scissors, or metallic instruments on the top of the telephone box. In a series-telephone this might cut out

the instrument; on the bridging line it might result in all the instruments on the line being thrown out of service. Where carbon lightning arresters are used, carbon dust sometimes collects in the air gap and causes short circuits and grounds the line wires more or less. To remove this source of trouble, slip out the carbons, blow off all dust, and replace them.

A very short list of only the most common faults that occur in ordinary series and bridging instruments, with suggestions as to their cause, is here given.

53. Cannot Ring or Receive a Ring.—The line or generator circuit may be opened in a series-instrument or short-circuited in a bridging instrument. If this trouble occurs in a series-bell, connect the two main binding posts together; if then the bell will not ring when the generator is operated, the trouble is probably a broken wire inside the box. For a bridging instrument, remove the two line wires at the top of the instrument; if now the bell will ring, the trouble was due to a short circuit outside the instrument, probably between the line wires. On a bridging ground-return system the line may be grounded.

54. Can Be Called, But Cannot Call Others.—This may be due to a weak or defective generator, such as a short or open circuit in the generator armature or circuit, or to bell coils of different resistance on the same line. If a call from another station rings the bell loudly, but the home generator rings its own and other bells weakly, the trouble is probably due to a weak generator, poor connection in the generator circuit, or partial short circuit of the generator armature. On a grounded, bridging, party-line system it may be due to a high resistance in the ground connection at the home station only; for this high resistance may cause such a decrease in the current sent out by the home generator that when it subdivides through all the other bells, each part is too feeble to ring any of them, whereas the small incoming current may still be large enough to ring the bell.

55. Cannot Be Called, But Can Call Others.—This may be due to imperfect adjustment of the bell, armature, or

gongs, or to bell coils of different resistance on the same line. In a bridging instrument, it may be due to a broken wire in the bell circuit, or to a defect in the automatic cut-in device of the generator. In a series-instrument, it may be due to a short circuit around the bell.

56. Magneto Rings Other Bells Properly, But Its Own Bell Feebly.—A defective bell may be due to a weak magnet or a poorly adjusted armature.

57. Bell Capable of Ringing, But Cannot Be Rung From Distant Station. The line, if a grounded-return system, is grounded; if a metallic-circuit system, the two line wires are crossed, or both are well grounded.

58. Weak Ringing of Bells.—This may be due to loose connections, bad joints in the line, or imperfect ground connection at terminals in case a ground return is used; a cross on line, if bridged metallic; by ground, if bridged-grounded line. If party line, it may be caused by several parties listening. The bell adjustment also may be defective.

59. If Clapper Clings to One Gong. Move that gong toward the other gong and against the clapper A slight adjustment of this kind will usually remedy the difficulty.

60. Instrument Receives and Transmits Rings, But Nothing Can Be Heard at Either Station. This may be due to loose connections or a broken wire in either receiver, in either receiver cord, in either secondary winding of the induction coil, or to poor or loose contacts in either hook switch, or to weak batteries, improperly connected cells, open or short circuits in primary circuits at both stations, or short circuits in both receivers or in the secondary windings of both induction coils. With a series-instrument, the following test may be made to determine whether the trouble is in the receiver or cord. Disconnect the cord from the box, but allow the receiver to remain on the hook. Remove the line wires from the binding posts and place the two ends of the receiver cord in the line binding posts and turn the generator handle; if the receiver or cord circuit is not broken, the bells will ring. The wires in a cord may be broken, and yet the

break may not be apparent if the cord is held in a certain position; hence, move the cords when making the test. If either conductor is broken, a scraping sound is produced in the telephone, or it may interrupt the speech so that a word is only audible occasionally. In a bridging instrument using a ground return, this trouble or difficulty in hearing at both telephones may possibly be due to imperfect ground connections at either or both stations, the ground connections at the several other instruments on the same line being good.

61. Can Hear, But Cannot Be Heard.—In such cases, the trouble is usually in the local-battery, or transmitter, circuit. A careful examination of all connections therein should be made. It may be due to a defective, packed, or improperly adjusted transmitter, exhausted battery, cells improperly connected, broken wire or short circuit in the battery circuit, or a short circuit in the secondary or primary winding of the induction coil. The person using the telephone may stand too far away from it; one should stand so that the lips are about 1 inch from a granular-carbon transmitter. The trouble may also be due to a defective receiver at the distant telephone, such as weak magnets, improperly adjusted receiver, dented diaphragm, or short circuit in receiver or in receiver cords.

62. Cannot Hear, But Can Be Heard.—In such cases, the trouble is usually in the receiver circuit, and is probably due to a defective or improperly adjusted receiver, dented diaphragm, or to a short circuit in the receiver coil or in the receiver cords. It may, however, be due to a defective transmitter or a weak or improperly connected battery at the transmitting station.

63. Weak Receiver.—A weak receiver may be due to poor connections in the receiver circuit, to partial short circuit, to a bent or dirty diaphragm, to the diaphragm being too close or too far from the pole pieces (usually it should be .015 inch from the faces of the pole pieces), or to a weak permanent magnet, which normally should support an 8-ounce iron weight or hold the diaphragm by its edge.

64. Rasping, Grating, or Sizzling Noises in Receiver.—This trouble may be caused by loose connections or excessive current in the battery circuit, by a buckled diaphragm in the receiver, or by particles of foreign substance lodged between the diaphragm and the pole piece of the receiver. Or, the position of the diaphragm may not be correct. In modern receivers, no provision is usually made for adjusting the distance of the diaphragm from the magnet; where such adjustment is possible, the diaphragm should be .015 inch from the magnet. Or, it may be due to a weak magnet; the magnet should at least be strong enough to hold the diaphragm by its edge. It may be due also to a live wire of a power, electric light, or other circuit lying across the telephone line.

65. Bell Rings Frequently Without Apparent Cause.—The line wire swings across telegraph or other live wires. On some selective-ringing party-line systems, a bell will give a tap when another bell on the same line is being rung, especially if some receiver at another instrument on the opposite side of the line is off the hook. When the ground is used as one side of the ringing circuit, bells will sometimes give a few taps when the line to which it is connected forms a better return to the exchange than the ground between the exchange and some other instrument that is being rung. Sometimes this may be remedied by putting an extra bell (removing the moving parts and gongs), or an impedance coil, in the circuit between the bell and the ground.

66. Poor Hook-Switch Contacts.—The hook switch is the cause of many complaints, which are generally due to dirty contacts or weak springs, and can be found and remedied very easily by cleaning or retempering the springs. The latter may be done by heating the spring to a red heat and then dipping it into water; if this makes too hard a spring, it may be softened slightly by using oil instead of water.

67. Testing Magneto-Generators.—One way to test a magneto-generator consists in placing the fingers across the

terminals and turning the crank; if the generator is in proper working order, a shock will be felt. This method of testing is preferred by some because if the magneto is bridged, the ringer might be open and the generator in good order, nevertheless. To test a series-bell and generator, place a piece of metal across the binding posts of the telephone, and turn the crank; if the bell rings, the generator is in good order; if not, the trouble is inside; but this is not specific, and both this and the former tests should be made. Assume that the latter test has been made and that the bells did not ring clear and strong, but that when another generator was used to send a current through the defective magneto, the bell in the latter rang all right; and that when the wires were taken off the terminals it tested clear, that is, the bell did not ring. If taken apart and examined closely, it will probably be found that the trouble is due to the automatic cut-out on the armature not working properly.

If no shock can be felt, the fault will be due to a short circuit (crossed wires) or to a broken wire; if, however, a shock is received, but the bell does not respond, then the fault is in the ringer and may be due to bad adjustment, or broken or crossed wires; if the shock is weak, it may be due to defective or weak magnets, or to a partial short circuit in the generator armature. All contacts in generators should be made and kept tight, and the springs should be examined often, as holes are frequently worn in them and cause trouble. Very little oil should be used, as it is liable to cause trouble. Magneto-generator troubles are usually easy to locate by making the above tests.

68. Induction-Coil Troubles.—A writer in "Sound Waves" says that the troubles likely to occur in an induction coil are: (1) an open secondary; (2) a short-circuited secondary; (3) an open primary; (4) a short-circuited primary; (5) a cross between the primary and secondary. Where the secondary is open, one can neither hear nor make himself heard. If the binding posts of the instrument are short-circuited, no sound can be heard in the receiver by blowing hard against the

transmitter diaphragm. The test for an open circuit in the secondary may be made by means of the receiver and a battery, in circuit with the secondary of the induction coil. This test should be made, as it may be that there is an open circuit at some other point and the induction coil may not be at fault.

Where the secondary is short-circuited, one may hear, but cannot be heard. This will be the case also if the primary is open or short-circuited. If the induction coil is one with a high-wound secondary, it will be possible to detect the trouble by means of the click in the receiver, when the coil is in series with the battery and the receiver. The click will be much fainter with a good coil in series than with one that is short-circuited. A good method of testing is to turn the current from the battery through the coil and see if the core is magnetized. If the coil is short-circuited, there will be no magnetic manifestation. The short-circuited primary may be detected in like manner. It should be remembered that the receiver test should be applied first to see if the coil is open, and if not open, then the battery should be applied for a short-circuit test.

A cross between the primary and secondary may manifest itself in several ways, depending on the telephone circuit and also on whether the coil is crossed on one or the other end. Generally, one end of the primary and one end of the secondary are connected together. Then, if the cross is at the other end of the coils, there will be a weakening of the out-going transmission, caused by the current from the secondary being partially short-circuited through the primary. To test for this cross, disconnect both ends of one of the windings, and, with the receiver and battery, test between the two windings; there should be no receiver click. If the cross between the primary and secondary should cut out but half of the secondary, there would not be such a notable difference in the transmission, and it may be hard to detect. Sometimes it is very hard also to detect partial short-circuiting of either the primary or the secondary coils. In fact, the measurement of the resistance will be the only means of detecting this trouble.

69. To Locate Open Circuits in Transmitters.—An open circuit in the transmitter of a local-battery telephone may be located as follows: Work the hook switch up and down while the receiver is held to the ear and the telephone is short-circuited at the binding posts; if there is no battery click and no trouble in any other part of the telephone, the transmitter circuit is open. Now short-circuit the connections to the transmitter, and if a click is heard in the receiver when the hook switch is raised, there must be an open circuit in the transmitter itself.

70. To Locate a Short Circuit in the Transmitter. To locate a short circuit in the transmitter proceed in the manner indicated in Art. **69.** If the transmitter is short-circuited, a stronger click will be heard in the receiver when the hook switch is raised or lowered than when in its normal condition. The voice will not be transmitted at all if the transmitter is short-circuited. Both the voice transmission and click tests are required to determine whether the transmitter is short-circuited; for if the click test only is tried, the click may be louder than normal because the transmitter is packed and takes a greater current than usual. If only the transmission test is tried, the voice may not be transmitted because the transmitter may be open, or the induction coil defective, due to a short circuit of either the primary or the secondary, or to an open circuit in the secondary winding. When the diaphragm is one terminal and the frame the other, a transmitter frequently becomes short-circuited by a metallic particle falling between the diaphragm and the transmitter front, which is often due to sticking a lead pencil into the front of a transmitter and breaking off the lead point. A short circuit may also occur when the rubber around the diaphragm edge becomes old and hardened, or when an insulating tip comes off the damping springs, or an insulating bushing becomes cracked.

71. Inspector's Outfit.—The following list of tools and materials for setting up and repairing instruments will be found very handy. Although not complete for all, and

too complete for some, work, it can be added to, or subtracted from, as may be found necessary: One pair long-nosed 5-inch pliers; one small hammer; three screwdrivers, 6 inches long, blades of different sizes; one keyhole saw; one set of drills; one pair of tweezers; three small files; one pair side-cutting pliers; one box of fuses; one box of screws, tacks, washers, staples, etc.; one ratchet brace; one set of bits, $\frac{1}{2}$-, $\frac{5}{8}$-, $\frac{3}{4}$-inch; one small can of oil; emery paper, or cloth, size 0000; crocus cloth; cloth and polishing paste; black insulating tape; 8-ounce weight for testing strength of receiver magnets; soldering lamp, iron, solder, and flux; small dusting brush; receiver and transmitter diaphragms and granular carbon; insulated and bare wire; candle or small lamp; battery material, battery gauge (the last two are for local-battery instruments only); satchel for carrying the above tools and material.

INSTALLATION OF TELEPHONES

TELEPHONE SYSTEMS

1. Telephone lines are known as grounded circuits, common-return circuits, and metallic circuits. **Telephone systems** may, therefore, be divided into *grounded-line systems*, *common-return systems*, and *metallic-circuit systems*.

GROUNDED-LINE SYSTEMS

2. Circuits.—In the earliest telephone lines, the fact discovered by Steinheil, in 1838, that the ground, or, as the English express it, the earth, could be used as a return conductor for completing a circuit between two points, was made use of. Therefore, a single wire was run between the points to be connected, as one side of the circuit, while the other side was formed by the earth, in the same manner as is now universally employed in telegraphy.

The arrangement of a group of lines radiating from a central office, using an earth return in the case of each line, is shown in Fig. 1, in which S^1, S^2, S^3, etc. represent the subscribers' stations, at which are placed complete telephone sets, comprising the usual talking and signaling apparatus. Each station is connected by a line wire L^1, L^2, L^3, etc., with a signal-receiving device D^1, D^2, D^3, etc., usually consisting of some form of electromechanical annunciator. The line wire in each case passes to one terminal of the subscriber's telephone apparatus, the other terminal of which is grounded, as at G^1, G^2, G^3, etc. In a similar manner, the other end of each line wire is connected to one terminal of its annunciator, the other terminal of which is connected with the ground at

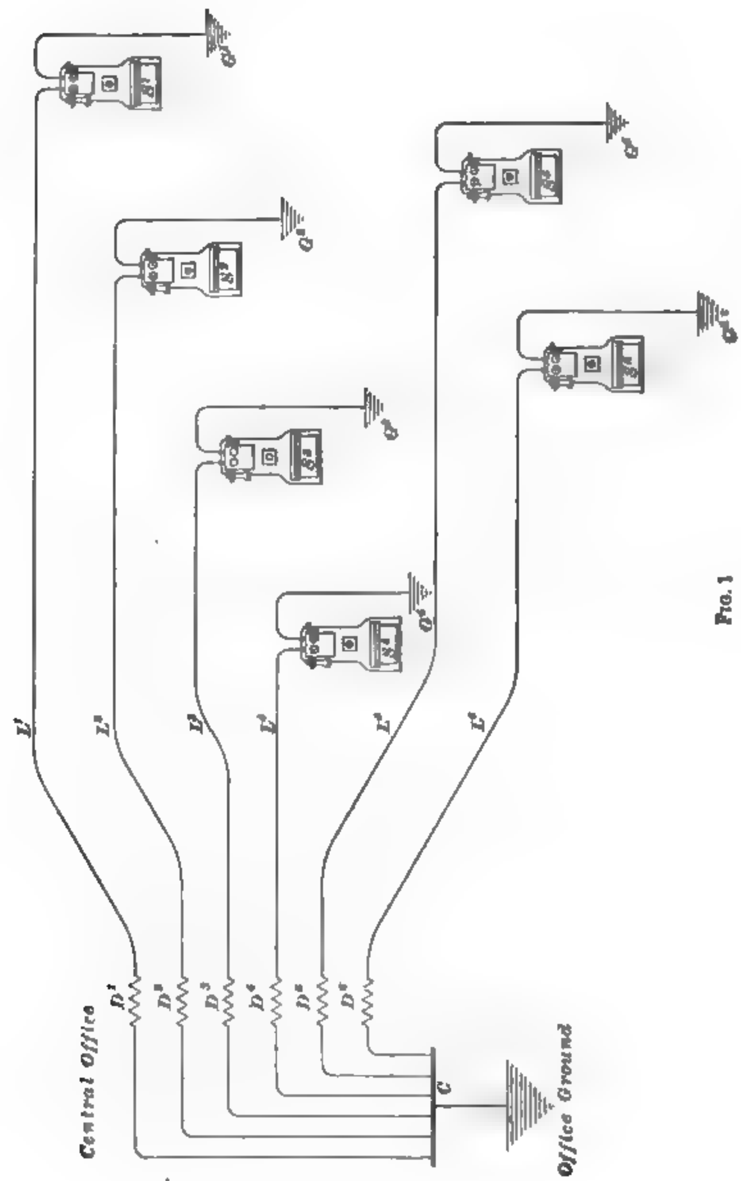


FIG. 1

the central office. Instead of forming a separate ground for each wire leading from the annunciators at the central office, all these wires may be attached to a common conductor C, which is itself grounded at the office.

3. Induction on Grounded Systems.—Systems arranged on this plan are subject to many difficulties that are not apparent at first sight, but the removal of which, without departing from the system of ground connections, has so far been found to be impossible. These troubles are due, in the main, to inductive action between other wires and the telephone wires, and between the telephone wires themselves. An electric-light wire, or any other wire carrying fluctuating currents, running parallel with the telephone lines, will affect them by induction, causing currents to flow to and fro in them, thereby producing noises in the telephone receivers to such an extent as often to render conversation impossible.

When the induction takes place between two such telephone lines, the result is that whatever conversation is carried on over one line may be heard on the other; this phenomenon is called **cross-talk** and is one of the chief difficulties with which the telephone engineer has had to deal. The fact that induction takes place between two lines is often extremely puzzling to the uninitiated, and frequently leads to the supposition that the two lines may be in contact with each other at some point, or crossed, as it is usually termed. This conclusion, however, is unwarranted, for inductive action is rather facilitated than otherwise by the fact that the two lines are not in actual contact. However, cross-talk is sometimes caused by leakage between two complete metallic circuits in a damp or wet cable.

4. Leakage.—Another cause for noises heard in telephones connected to grounded lines is due to a form of leakage. Sometimes this is due to a portion of the current flowing in a neighboring wire finding an easy path to the telephone wire on account of the poor insulation between the two, and then to ground through the telephone instruments, thus causing a noise similar to that produced by

induction. A more frequent form of leakage, however, is that from grounded electric-power systems, of which the electric railway is the most usual type. A current from the railway system following the earth return is intercepted by the ground plate of a telephone station, and thence part of it continues through the ground as before and another part passes through the ground connection of the telephone, the telephone instruments and line, and again to earth through the ground connection at the other end. A very slight difference of potential at the terminals of the telephone line, due to the use of the earth return in electric-railway systems, will cause currents to flow in the telephone line that will set up the noises already referred to, and often entirely prohibit the use of the telephones on the disturbed lines.

RESISTANCE OF THE EARTH

5. The most prolific source of trouble on grounded telephone lines is bad ground wires. Weak and non-ringing of bells and faint talking will frequently be caused by bad grounds, when the cause is attributed to faulty bells, microphones, or hand telephones.

6. A given battery will produce in a long circuit composed of two line wires, the earth not being used as a return path, a certain current; but if the earth is used as one path in place of one line wire, and good ground connections are made at both ends by means of large plates of the same material placed in moist soil or running water, the current with the same battery will be almost doubled. Hence, the resistance of the circuit has been reduced to about one-half its former value, from which it appears that the earth has but very little resistance. Although the length of the earth circuit may be large, its sectional area is relatively very great and its resistance should be small. But if the line is short, and the line resistance small as a result, the resistance of the earth may be quite appreciable, showing that the earth resistance is not zero and is only a negligible quantity when the resistance of the line circuit is large.

Several things may cause the resistance of the earth circuit to be appreciable. In the first place, the current meets with opposition in passing from the plates to the earth, and this opposition is entirely independent of the distance between the two ground plates. It depends only on the surface area, the material of the plates, and the nature of the soil in which they are buried. Since the resistance of the earth itself is usually very small, the resistance from plate to plate, if they were always buried in the same kind of soil, would be about the same for all distances, and this resistance would be practically the contact resistance between the ground and the two plates. Practically all the ground resistance is generally located at these contact surfaces.

When the ground plates are placed in dry earth, and especially in a region where the soil and substrata are very much poorer conductors than usual, the earth circuit may have quite a large resistance. If the plates are too small, the contact resistance between the plates and the earth may also be appreciable.

7. From long experience, it has been found that the resistance of the earth varies considerably. In a sandy soil, at about the level of the sea, Sinclair says it is almost impossible to get anything like a good ground, while with a clay soil it is almost impossible not to get a good ground. He also says that it is easy to establish an earth connection between two points 50 to 100 miles apart, but it is an altogether different matter to do so when they are only ½ mile apart.

In some regions, on account of their geological character, it is very difficult to secure a sufficiently good ground connection. In such a case, a return line wire may be advantageously used part of the way, until a locality is reached where a good ground can be obtained. Cases are on record in certain anthracite regions, and in some rocky, mountainous districts, where it was found almost impossible to make grounds that would not offer an abnormally high resistance.

8. According to a measurement made by DuMoucel, the resistance of the earth under favorable circumstances was

about 108 ohms. Experience in America indicates that the resistance of the ground return on a circuit of average length, or over, with ground plates buried in moist earth, should not exceed about 10 ohms, and is often as low or lower than 1 ohm, provided that the intervening region is not too rocky, full of coal, or sandy.

A resistance of 10 ohms is equivalent to about ½ mile of No. 9 B. W. G. iron wire. Hence, considering the electrical efficiency only, it would not pay to use the earth as a return circuit if the resistance of one line was less than 10 ohms. Commercial efficiency, however, is another thing. An earth return could be used profitably on a much shorter line circuit, if it were necessary to consider only the resistance, cost of construction, and maintenance of the second line wire. But on account of the disturbing noises that are produced in a single conductor by neighboring electrical circuits, it is no longer considered good practice to use a ground return for a telephone circuit. However, good ground connections are necessary not only for ground-return systems, but also for all lightning arresters, with which most telephones and all exchanges are provided.

MEASUREMENT OF GROUND RESISTANCE

9. Measurements to determine the resistance of the ground between two points are not very reliable, on account of the presence of polarization or chemical action, which it is quite difficult to eliminate. Moreover, in no two places would the resistances be necessarily equal, even with the same plates and the same distance between them.

10. Measurement by a Voltmeter.—The only instrument required for measuring ground resistance is a reliable voltmeter whose resistance is definitely known. The method to be given is especially convenient when the two points between which the resistance is to be measured are so near together that the resistance of connecting wires may be so small in comparison with the resistance of the voltmeter itself that their resistance can be entirely neglected. If their resistance is not small enough to be neglected, it must be

measured and proper corrections made for it. This renders the method rather inconvenient, but it is very seldom that their resistance need be considered.

It may be well to state that the current passing through a voltmeter, multiplied by its resistance, gives the difference of potential at the terminals of the voltmeter. But this is also given directly by the reading of the voltmeter; hence, the reading of the voltmeter, divided by its resistance, gives the current flowing through the voltmeter. A low-reading voltmeter, one whose maximum reading is 3 or 5 volts, will generally prove the best in making this measurement. Very poor and inaccurate results will be obtained by trying to measure 1 or 2 volts, for instance, with a voltmeter reading as high as 150 volts. Let us assume that there may be electric street-railway, or trolley, currents flowing between the two plates, thus causing them to be at different potentials.

11. Suppose that there are two points A, B in the ground between which we wish to measure the resistance. At these points there may be ground plates, or at one point there may be the rail of an electric street railway and at the other the lead or iron armor of an underground cable, or a ground plate. First, connect the voltmeter directly between A and B. Then, if a sufficiently large trolley current is flowing from one point to the other through the ground, the points A and B will be at different potentials and we will probably get a small reading on the voltmeter, which we will call V. Second, connect a number of cells, the total electromotive force of which must not be greater than the largest reading on the voltmeter, between the points A and B. The voltmeter is also connected between A and B, and it now gives a reading V_1, which is evidently the total difference of potential between the terminals of the battery. Third, connect the voltmeter and the same battery in series between the two points A and B. The voltmeter gives a reading V_2, and the current through the voltmeter in this position we will call I_2. Therefore, if r is the resistance of the voltmeter and x is the resistance of the ground between the two points A and B, we will

have $I_2 r + I_2 x$ = difference of potential at battery terminals ± difference of potential between points A and B that would be caused by the trolley current alone. The sign ± is used because the difference of potential between the points A and B that the trolley current tends to set up may be in the same direction (+) or in the opposite direction (−) to that due to the battery alone. Then we may write

$$I_2 r + I_2 x = V_1 \pm V$$

but $I_2 r = V_2$ and $I_2 x = \frac{V_2 x}{r}$; hence, $V_2 + \frac{V_2 x}{r} = V_1 \pm V$. Solving this for x, we get

$$x = r\left(\frac{V_1 \pm V}{V_2} - 1\right) \qquad (1)$$

When there is no electric-railway or other stray current flowing between the two points A and B, then $V = 0$, and the formula reduces to

$$x = r\left(\frac{V_1}{V_2} - 1\right) \qquad (2)$$

12. This is a very convenient and practical method and one that is very useful also in determining how much current may be flowing from the lead or iron armor of an underground cable to the surrounding ground. From this it may be determined whether there is much danger to the lead or iron armor from electrolysis, and just where the corrosion is greatest. The corrosion may be reduced by permanently connecting, at the danger points, the lead or iron armor with the street-railway return feeders or rails by a good, stout copper wire.

GROUND PLATES

13. Material for Ground Plates.—The best material for ground plates is copper, because it does not corrode or rust away like iron. Ground plates may be made of sheet copper $\frac{1}{16}$ inch thick and having a surface of 4 or 5 square feet. The joint between the wire and the plate should be a good metallic connection, preferably riveted and well soldered and covered with a moisture-proof paint, to prevent

local chemical action, which causes an eating away of the metals at the joint. Ground plates may also be made of sheet zinc or heavily galvanized sheet iron, but they will not last, especially the latter, as long as copper plates. Some use, at a substation, iron rods driven deep enough into the ground to always reach moist earth; for lightning-arrester grounds, this may be sufficient. To prevent the corrosion of a wire leading to a ground plate, the wire should be coated with a good moisture-proof insulating material, such as rubber. The permanent ground wire at an exchange should not be smaller than a No. 8 copper wire.

14. Location of Ground Plates.—When practicable, place the ground plate in a good well, with a weight at the bottom to keep it in place. If a constant stream of water can be conveniently reached, that is still better. A cistern is of no use for this purpose, for it is merely a tight vessel for holding water, and the contents have little or no connection with the surrounding earth. Where driven wells are used, scrape the top of the well pipe, wrap the ground wire firmly around it, and solder it on if possible. This makes a perfect ground connection, but it may be very difficult or impossible to solder the wire to the pipe, especially if there is any water running through it. Dry earth, sand, gravel, etc. are not conductors of electricity. Contact must be made with damp earth. It is not sufficient to put the ground plate a few feet in the earth, where in the summer the ground becomes dry, and in winter the earth freezes around and below it. Dry ice is an insulator, and a ground plate in frozen earth is absolutely worthless.

If a ground plate must be buried in a sandy, gravelly, or rocky soil, where the moisture is not sufficient to render it a good conductor, place the plate in a pit dug for the purpose and pack scrap tin or other waste metals or crushed coke or charcoal closely around it and lead the discharge from water or drain pipes into the pit.

15. Ground Connections Through Water and Gas Pipes.—Water and gas pipes, on account of their extensive

ramifications through the ground, make excellent contact with it, and for this reason are usually considered as good terminals to which the wire running to the ground may be fastened. Do not connect a ground wire to a gas pipe if, by going a little farther, a water pipe can be reached, nor to the nearest place on the water pipe if, by going a little farther, a pipe closer to the entrance of the building and outside of building joints can be reached. If the ground connection must be made to a gas pipe, it should be made on the street side of the meter if possible, or the meter should be bridged by a wire, since the meter is liable to be removed at some time or other, and thus break the ground circuit. Moreover, the white or red lead used in iron-pipe joints often makes the joints offer considerable resistance to the current before it can reach the ground.

It is not very desirable, where there are electric street-railway systems in the neighborhood, to make the ground connection through gas or water pipes. Water pipes used for this purpose on a short telegraph line near a trolley road have been known to become so weak as to burst inside of 2 months. The weakening was caused by electrolytic action due to the railway current returning through the pipe and the telegraph line circuit instead of through its normal path—the rails and the ground. Judging from a great many results that have been recently observed it seems to be doubtful if it is good practice to connect the ground wires with water pipes. According to some authorities, it is much better to run the wire directly to a plate buried deep enough in the ground to be always in contact with moist earth.

16. Soldering Ground Wires to Pipes.—The Underwriters advocate soldering the ground wire to a brass plug that can be firmly screwed into a pipe fitting. It is best before soldering to a water pipe to drain out all the water, as the result is more satisfactory and less tiresome and expensive. However, it is possible to solder a ground wire to a water pipe without turning off the water, notwithstanding statements to the contrary. To do so, it is necessary

to use a blow torch so that the surface of the pipe to which the connection is to be made shall be heated quickly to the proper temperature in order that the heat may not be conducted to portions on either side. Scrape both the wire and pipe clean and bright, the latter preferably with a file; wrap about 20 turns of the wire around the pipe, which should then be heated sufficiently to make the solder run freely between the turns of the wire. When cool, the joint should be taped. Care must be taken not to melt lead pipes.

17. Fastening Ground Wires to Pipes Without Solder.—If the owner of a building believes that a soldered joint will injure his pipe and will not allow one to be made, a good way to fasten a ground wire to a pipe is shown in Fig. 2, which was given in the American Telephone Journal. The pipe should first be thoroughly cleaned by filing until the surface is smooth and bright. Some advocate wrapping tin-foil around the pipe to prevent rust and chemical action. The ground wire should not be smaller than No. 16 B. & S., and should be cleaned thoroughly before wrapping around the pipe. Place the loop, as shown in the figure, parallel to the pipe, and wrap over it about sixteen turns of the free end of the wire. Then, draw the end *a* through the loop and pull tightly on the end *b*, thus pulling the loop under the wrappings so as to hold the end *a* securely. To make this tie still more secure, it may be soldered, otherwise it is advisable to cover the turns with tin-foil and wrap tape over the joint in order to prevent the entrance of moisture.

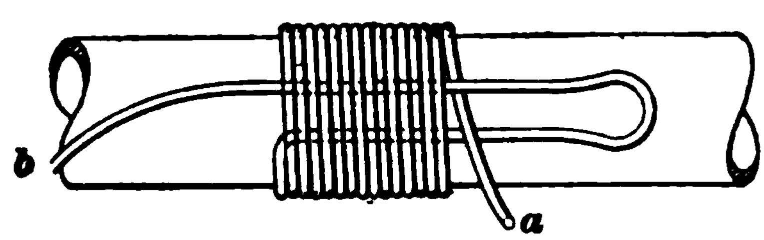


FIG. 2

Some claim that a ground clamp or a plastic alloy, such as the Edison plastic alloy paste, is fully as good if not preferable to a joint made by soldering the ground wire to a water or gas pipe.

COMMON-RETURN SYSTEMS

18. Circuits.—As a partial remedy for the difficulties brought about by the grounding of circuits, a system has come into wide use in which a wire common to several or all of the circuits forms the return instead of the earth. This system is generally known as the **common-return** or **McCluer system**, the latter name being that of its originator. In Fig. 3 is shown, diagrammatically, the same group of stations S^1, S^2, S^3, etc. as was shown in Fig. 1, connected by line wires L^1, L^2, L^3, etc. with the switchboard drops or other signaling devices D^1, D^2, D^3, etc., in the same manner as in that figure. Instead, however, of using an earth return for these circuits, each line wire is connected at each end, after passing through the instruments, to a common-return wire, which passes from the central office, following, as closely as possible, the same route as the line wires L^1, L^2, L^3, etc. In order to shorten up the various leads l^1, l^2, l^3, etc. that connect the stations with the common-return wire, the common-return wire may itself be branched so as to pass near to the various stations. In practice, several common-return wires, all connected together at the exchange, are sent out in various directions from the exchange, following the route in each case of its own group of line wires as much as possible. It sends off lateral branches wherever necessary to facilitate the work of connecting the various stations to it.

19. Advantages of Common-Return System.—If a common-return system is free from grounds, with the exception of a single ground connection that is sometimes placed on the common-return wire at the central office, the leakage difficulty is almost entirely done away with. The induction between the various telephone lines, and also between other lines and the telephone lines, is greatly reduced, because the common-return wire is acted on also by the inductive influence and, as it forms the return side of each circuit, has a tendency to neutralize the inductive action in the lines themselves.

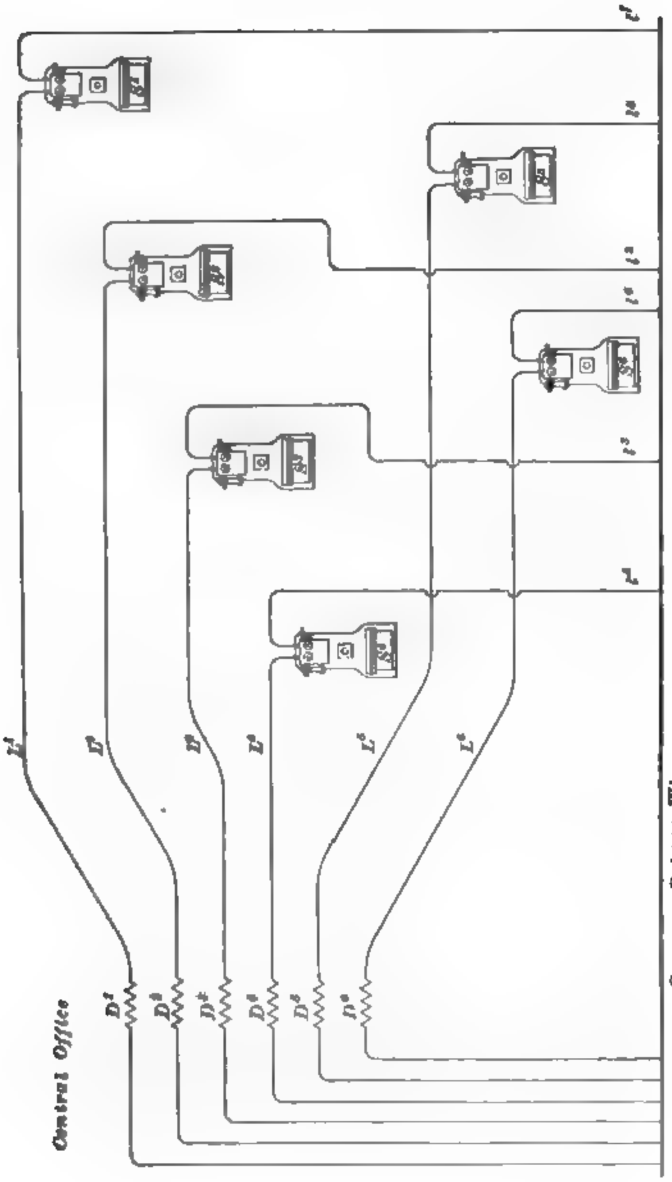


Fig. 3

20. The principal point to be considered in the construction of common-return systems is the proper size of the common-return wire. In Fig. 4, *D*, *D*, *D* represent the drops at the central office, *R*, *R*, *R* the telephone apparatus at the subscribers' stations *1*, *2*, *3*, *4*, etc.; *C. R.* is the common-return wire, which completes the circuits of the various line wires L_1, L_2, L_3, etc. between the central office and the various subscribers' stations. With such an arrangement, it is evident that the return circuit for any one line is made not only from the common-return wire, but through all the other wires in multiple. To illustrate: A current set up in the apparatus at station *3* will pass over line wire L_3 to the central office; from here the greater portion of the return

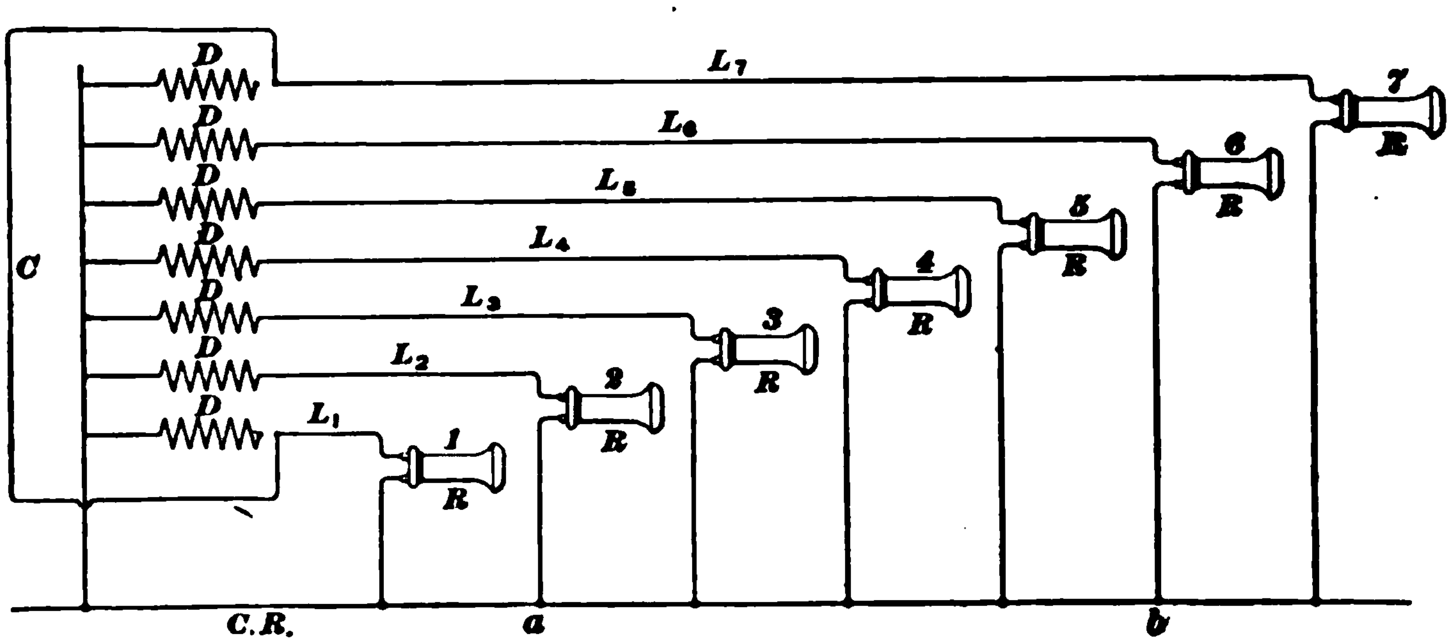


FIG. 4

current will pass through the common-return wire, but paths are also offered through the line drops and the line wires of the other stations *1*, *2*, *4*, *5*, *6*, *7*, etc., to the common-return wire, and back to station *3*. It is evident that, if the resistance of the common-return wire is not very low, it may serve to shunt enough current through the other telephone lines to cause cross-talk. This is the principal reason why the common-return wire should be made of low resistance, and it is evident that the lower the resistance, the more perfect will be the freedom from this leakage cross-talk. Of course, when two lines, L_1 and L_7, for instance, are connected for conversation, they are disconnected from the line drops and connected together by a cord circuit, such as is

shown at C, this circuit connecting the line of station *1* with the line of station *7* for conversation. Currents generated at either of these telephone stations will pass through the two line wires and the cord circuit, the return circuit of least resistance being through the common-return wire $C. R.$ It will be evident, however, that a portion of the return current may be forced through the other lines in multiple with the common-return wire. Thus, a part of the current that should flow in the common-return wire from a to b might be shunted, by the resistance of that portion of the common-return wire, through the instrument at station *2*, line wire L_2, drop D of that line, common connection of the central office, drop D of L_6, line L_6, and the instrument at station *6*, to the point b.

21. Size of Common Return.—No general rule can be laid down for the determination of the size of the common-return wire, but where the line wires are of copper—say No. 12 or No. 14—a No. 6 or No. 8 common-return wire will usually prove large enough, although where a branch of the common-return wire serves a large number of subscribers and extends to a considerable distance from the central office, a No. 4 would be found to give better results, at least for the main common-return wire. The greater the resistance of the exchange line signal, the average resistance of the line wires, and the subscribers' bells, the smaller can be the common return.

As far as electromagnetic or electrostatic induction between the telephone lines themselves or between the telephone lines and foreign circuits are concerned, there is no advantage to be gained by making the common return larger than the individual telephone wires; in fact, the same size would be preferable. Since all the line wires, except one, form paths in parallel with the common return, it is usually necessary, in order to reduce the strength of the return current through each parallel telephone line to an amount that will produce no perceptible cross-talk, to make the common return larger than the individual line wires. It is,

however, useless to increase the size of the common return in order to reduce cross-talk that is due to leakage in cables or elsewhere, or to induction between apparatus or circuits in the central office.

22. **Cause and Remedy for Trouble on Common-Return Leads.**—It is good practice to have a separate common-return wire for each lead of wires, and to confine the common-return sides of all subscribers' lines on that lead to their proper common return. These branch common-return wires should, if possible, terminate in a switch at the central office, so that each one may be grounded, opened, all connected together and grounded, or all connected to the main common return without a ground, as may be found desirable.

A break or defective joint at one point on a common return usually produces the same result as a cross. If several subscribers apparently become crossed in one district and on the same return, it can reasonably be inferred that the return is open at some point, probably due to a break or a bad joint, between the exchange and the nearest subscriber's station. This can be determined by grounding this branch of the return system at one or more places between the exchange and the subscriber's station, until the trouble disappears. It is usual to halve the distance and keep on halving the bad portion until the fault is found. Trouble could more easily be removed by grounding the return at one of the defective subscribers' stations, and this is often done by careless workmen; but this method soon converts the system into a grounded return, and the beneficial result of the common return is lost. Such carelessness can usually be located in a system, when provided with switches as mentioned above, by connecting the various common-return leads to the ground at the exchange.

Trouble at the central office on a common-return system usually makes itself known by causing cross-talk or noise. The common return if crossed with a trolley or other high-tension circuit will generally produce a noisy condition on

nearly all the exchange lines. The cross can usually be located by opening each switch of the common return and observing the result. If very heavy, a spark will be noticed; if only slight, a change will be observed in the amount of the disturbance.

23. Similar Side of Each Circuit Connected to Common Return.—All the sleeve wires in an exchange using a ground- or common-return system should always be connected to the ground- or common return. For should a line with the tip side grounded or connected to a common return be joined through an exchange circuit to a line with the sleeve side grounded or connected to a common return, a short circuit will be produced, as shown in Fig. 5, from the tip side of the wrongly grounded exchange conductor *c*

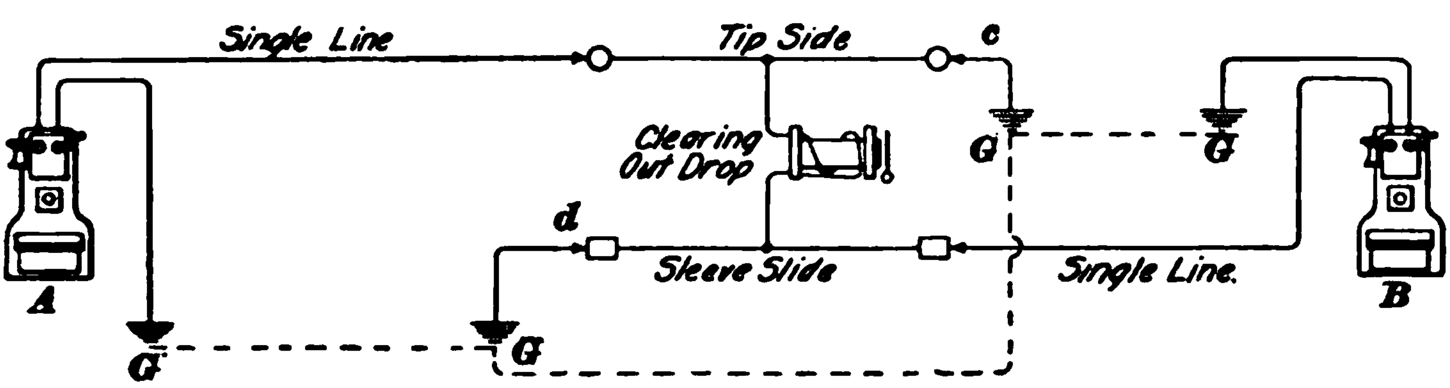


FIG. 5

through the common or earth return to the sleeve *d* on the other end of the exchange circuit. The dotted lines represent the earth, or common, return circuit. On account of the low-resistance path through the earth or common return across the circuit, no conversation can take place between the connected subscribers, neither can they ring down the clearing-out drop for disconnection. The lines will of course remain tied up until the operator discovers the trouble. Therefore, care should be taken not to connect some sleeve and some tip wires in the same exchange to the ground- or common-return wire. In Bell systems, the wires in a cable that are evenly numbered are connected to the common return or ground, the odd-numbered wires being connected to the open overhead line wires.

METALLIC-CIRCUIT SYSTEMS

24. Circuits.—In reality, the common-return system just described is one form of **metallic-circuit system,** because the circuits are completed entirely through metallic conductors. From common usage, however, it has become customary to refer to only those lines that have individual return wires, as metallic circuits. In a metallic-circuit system, therefore, two lines are extended from the central office to each subscriber's station. These lines are of the

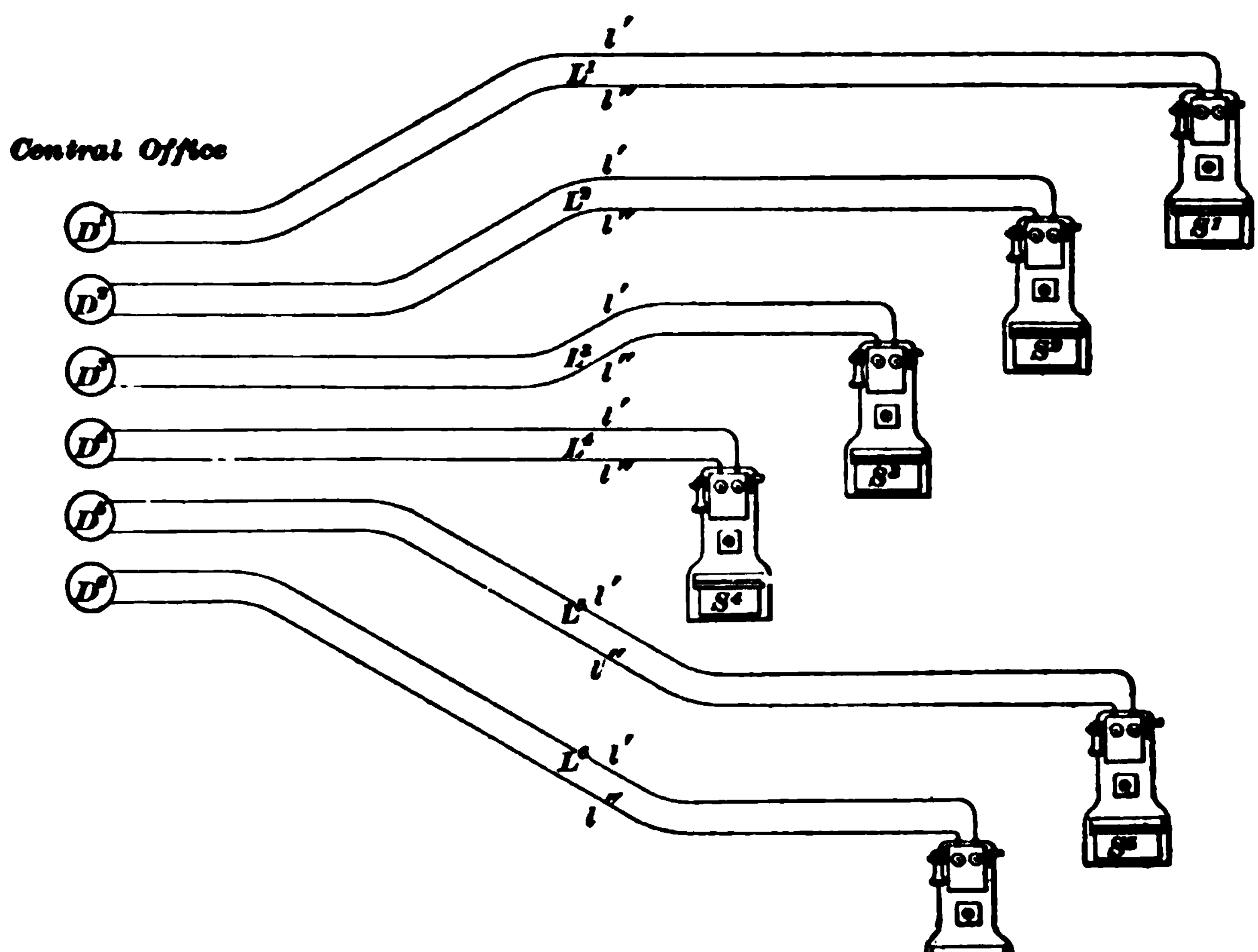


FIG. 6

same size, and are placed, as far as possible, in such manner as to be equally distant from all disturbing sources, such as other wires. A group of stations S^1, S^2, S^3, etc., connected by complete metallic circuits with the central-office signaling devices, is shown in Fig. 6. Each metallic circuit L^1, L^2, L^3, etc. is composed of two wires l', l''.

It is sufficient at this point to say that the metallic circuit alone has completely and satisfactorily solved the various problems arising from induction between the telephone lines

themselves, and also from wires carrying other kinds of current. The construction of metallic circuits throughout a system, of course, involves considerable expense, and where this cannot be well afforded, the common-return system may be used, which, if properly and carefully designed, is capable in systems of moderate size of giving very satisfactory service. A grounded-line system should never be used, except in the smallest exchanges, where the lines are short and where there are no electric railways or electric-lighting systems.

25. Metallic Circuits in Exchanges and Cables. Although ground-return and common-return systems may be used for the distribution of circuits outside the exchange building, it is no longer considered good practice to use any but a complete metallic-circuit system within the building and through the cables. In order to reduce cross-talk as much as possible, each telephone circuit should consist of two separate wires (twisted spirally about each other) throughout the exchange and all cables to the terminal box where the open-wire construction commences. At this point, all wires forming like sides of the various circuits in the exchange, which are usually insulated with the same color material, may be connected to one wire, usually not smaller than a No. 8 B. & S. copper wire, which would be connected to the common-return wire of the system, or to a good ground if a ground return is used. This will give a metallic circuit of twisted wires for each line to the open-wire part of the system.

If the wires are connected to the common conductor anywhere inside the exchange building, and each conductor of the outside cable is used as a line wire, the cross-talk will be greatly increased. This is due to the fact that the cable conductors will then be in the condition of parallel line wires without transposition, which will be fully explained later, and the electrical induction from any one of them carrying voice currents will affect the remainder in the same cable, and thus bad cross-talk will result. This induction cannot exist between lines made up of twisted-pair circuits. In other

words, the two wires forming a twisted pair in a telephone cable should never be used for two telephone circuits with either a ground or a common return.

The construction of the line circuits of an exchange will be considered elsewhere, it having been thought best at this point to give some preliminary ideas of the various types of lines.

INSTALLING TELEPHONES

26. Under this heading will be considered the work of fastening the telephone in its proper position in the subscriber's premises, properly adjusting its parts, connecting it to the line, and placing it in service. The nature of the work of instrument setting depends on two factors: first on the nature of the telephone; and second, on the location of the telephone.

27. Installing Wall Telephones.—The chief points to be observed in putting up a wall telephone set are to place it against a solid wall, so that no ordinary vibration of the building shall affect it; and in such a position, as regards neighboring objects, that the receiver and bell-crank may be easily reached; and as regards height from floor, so that those who will require to use it most can speak to the transmitter without undue stretching or stooping.

The user of the telephone will generally indicate the most convenient place for it, and his wishes should of course be respected, provided that the instrument will have a fair chance in the position selected. If it is obviously unsuitable, this should be pointed out and explained, in the interest of the customer himself. Any situation that will cause the telephone to be in the way of office traffic should be avoided, both because of the risk of the instrument getting damaged by accidental collision and because of the annoyance to one using the telephone from having people pass close by frequently. The best place for an office telephone is in a small closet, booth, or space partitioned off for that purpose. Booths are now made in many styles. Those with double walls, doors,

and windows are practically sound-proof; that is, a person outside cannot hear the person who is talking inside the booth.

28. Wall sets are placed on wood, brick, or plastered walls. In the former case, all that is necessary is to fasten the telephone at the proper height by wood screws about 1½ inches long passed through four holes, one at each corner, of the instrument board. Where the wood to which the instrument is to be fastened is hard, like oak or mahogany, it is well to coat the end of the screws with soap moistened with water, as this insures their easy passage into the wood and does not prevent a firm hold. The telephone can usually be fastened to a plastered wall by screws; sometimes extra long ones are required. The screws should go into solid wood or at least firmly into the lath and not merely through the plaster between the lath.

Fig. 7

Where the walls are of hollow firebrick, the instrument can be secured in the same manner as explained for wood, except that the screws should be longer—about 2½ inches long. If the wall is of hard brick, it is impossible to drive screws into it, except in the lines of mortar. Under these conditions it is best to first nail up a board a trifle larger than the instrument board, called a backboard, using tenpenny nails, and screw the instrument to this. This method has the additional advantage that, when the telephone is removed, it is simply unscrewed from the backboard, allowing the latter to remain fastened to the wall. The premises are thereby left uninjured. Some building superintendents require that brick and plastered walls should be plugged before the telephone is set. This is done by the use of a hammer and star drill, which is a chisel having two cutting edges at right angles, as shown at *a* and *b*, Fig. 7. By the proper use of this tool, a neat, clean hole may be cut about 6 inches deep. These holes should be located opposite to where the screw holes in the instrument board are to come

when the latter is in place. Into each hole is then driven a cylindrical plug of soft pine, of such size as to make a binding fit, and hammered or cut off flush with the wall. The instrument is then secured to these plugs. Telephones should not be mounted on a chimney breast by plugging the wall with wood, as the latter will dry, shrink, and become loose.

29. Location of Batteries.—Batteries for use with a wall instrument may be placed in a suitable box on the floor directly under the instrument, or, if required by the subscriber, they may be placed in a near-by closet, or under a washstand. If possible, the batteries should be located so as to render access for renewals easy. In setting common-battery instruments, the same instructions apply. There being no batteries, however, at the telephone, the work is very simple, all that is required being to connect the line wires to the proper terminals and to run a ground wire.

30. Installing Desk Sets.—The induction coil, when mounted on a separate connecting rack or block, should be securely mounted by means of screws through holes in each corner under the desk or table on which the desk stand is placed. The generator box is screwed underneath the desk or table in such a position that the crank of the generator is within easy reach. The particular points to be observed in installing desk sets are: that the induction coil shall be mounted where it cannot be seen nor subjected to mechanical injury, and near enough to the desk stand to enable the latter to be used by means of the stand cord furnished with it over as large an area as possible; and that the generator be so placed as not to be in the way, and yet be accessible for use. Both the generator and induction coil should be fastened as securely as screws will hold them.

31. Installing Cabinet Desk Sets.—The desired location having been learned from the subscriber, the cabinet desk set is placed with its back to the wall, the top of the apparatus cabinet is removed, and the line wires are brought in through the two small holes in the back and fastened securely to the binding posts. The batteries are then set up,

placed in the battery cabinet, and connected in series, their terminals being carried up through holes in the apparatus board to the proper binding posts. As the installer usually receives the set with the receiver and cord unattached, he connects these up properly, and the telephone is ready for service. If the floor under the set should be very uneven, it may be necessary to block up one side with a thin piece of wood to make the top of the set level. When this operation is necessary, it is well to fasten the set securely to the floor, using iron angles and screws. It is very seldom, however, that this is necessary.

INTERIOR WIRING FOR TELEPHONES

32. Under this heading is included the run of wire from the point of entrance to the subscriber's premises to the telephone. The fundamental principle to be observed in wiring for a telephone is to make the run as short as possible. It is therefore necessary for the instrument setter, before he starts his run of house wire, to ascertain from the subscriber the location of the telephone; and from the subscriber, janitor, or building superintendent the route over which the wire must or may be run. In residences and in the older type of office buildings, the nature of the house wiring is different from that found in the modern office building. In connection with the former class of buildings, some one of the many overhead distributing systems are used; while with the latter class, it is customary to run a house cable, with terminals on each floor, through a specially prepared wireway, flue, or elevator shaft, in which case wires need be run from each telephone only to the terminal on the same floor.

33. Where the distribution is from aerial circuits, the point of entrance to the building may be made anywhere at the discretion of the instrumentman, but it should be so selected as to make the drop wires—which are the wires running from the nearest pole or point of distribution to the building—the ground wire and the house wires as short as possible. With these objects in view, the cellar wall is now

generally considered the most advantageous place to pierce, thereby enabling the protecting device to be placed on the inside of the wall at the point of entrance, thus making the line from the protecting device to the ground as short as possible. Formerly, the proper place to attach the drop line was considered to be in the attic.

34. The National Electrical Code.—When electric lights first came into use, the insurance companies discovered that there were many fires of electrical origin, because the wiring was of very inferior workmanship. The various associations of underwriters, therefore, formulated rules in accordance with which they required that all wiring be done, or they would not insure buildings containing it. In the course of time, these various rules of local insurance associations were reduced to a uniform code, and, finally, they became known as the National Electrical Code, and received the indorsement of practically all the fire-inspection bureaus throughout the United States, besides that of many other organizations.

A few cities have rules of their own that differ slightly from this code, but the differences are not vital. Every wireman should be supplied with a copy of the latest edition of the National Electrical Code, and do work in the United States in compliance with those rules, whether additional laws exist or not. Copies of the code, and of all other information published by the Underwriters' National Electric Association for the sake of reducing the fire hazard, may be obtained by writing to the National Board of Fire Underwriters at Chicago or New York, or by applying to the nearest Underwriters' Inspection Bureau. The rules are revised as often as changes in the electrical art make such revision necessary.

In addition to this code of rules, the National Board of Underwriters publishes, about every year, a list of approved fittings and insulated wires for use in connection with the code. This list contains the names of articles that have been found entirely satisfactory by test or experience, together

with the names of the manufacturers. It does not contain a list of all fittings that will pass inspection, and many good articles are not listed in its pages.

In what follows, rules and explanatory notes taken from the National Electrical Code are indented (that is, set in a little from the edge of the other printed matter, as in Art. **35**, for instance) in order that they may be distinguished from other information also relating to the interior wiring of buildings for telephones.

UNDERWRITERS' RULES FOR SIGNALING SYSTEMS

OUTDOOR WIRING

35. The rules to be given here relate to the wiring for telephone, telegraph, district-messenger and call-bell circuits, fire and burglar alarms, and all similar systems:

> *a.* Outside wires should be run in underground ducts or strung on poles, and, as far as possible, kept off of buildings, and must not be placed on the same cross-arm with electric light or power wires. They should not occupy the same duct, manhole, or handhole of conduit systems with electric light or power wires.
>
> Single manholes or handholes may be separated into sections by means of partitions of brick or tile so as to be considered as conforming with the above rule.
>
> *b.* When outside wires are run on same pole with electric light or power wires, the distance between the two inside pins of each cross-arm must not be less than 26 inches.

36. Protective Devices.—

> *c.* All aerial conductors and underground conductors which are directly connected to aerial wires must be provided with some approved protective device, which must be located as near as possible to the point where they enter the building, and not less than 6 inches from curtains or other inflammable material.

The protective device should not be mounted close to gas or water pipes, or electric-light or other wires. Select a place as dry as possible and as near to the place of entering as possible and in a place easy of access, since they must be inspected occasionally. Protectors or any other pieces of apparatus should never be put up with nails, but with screws.

WIRING ON LINE SIDE OF PROTECTOR

37. Size and Kind of Wire.—

d. If the protector is placed inside of building, wires, from outside support to binding posts of protector, must comply with the following requirements:

1. Must be of copper, and not smaller than No. 18 B. & S. gauge.
2. Must have an approved rubber insulating covering.

38. Approved Rubber-Covered Wire.—The Underwriters require rubber-covered wire to comply with the following specifications:

(*a*) Copper for conductors must be thoroughly tinned.

(*b*) Insulation for voltages between 0 and 600 must be of rubber or other approved substances, and be of a thickness not less than that given in the following table for B. & S. sizes:

From 18 to 16, inclusive	$\frac{1}{32}$ inch
From 15 to 8, inclusive	$\frac{3}{64}$ inch
From 7 to 2, inclusive	$\frac{1}{16}$ inch
1 to 0000, inclusive	$\frac{5}{64}$ inch

Measurements of insulating wall are to be made at the thinnest portion.

(*c*) The completed coverings must show an insulation resistance of at least 100 megohms per mile during 30 days' immersion in water at 70° F.

(*d*) Each foot of the completed covering must show a dielectric strength sufficient to resist, throughout 5 minutes, the application of an electromotive force of 3,000 volts per $\frac{1}{64}$ inch thickness of insulation under the following conditions:

The application of the electromotive force shall first be made at 4,000 volts for 5 minutes, and then

> the voltage increased by steps of 3,000 volts, each held for 5 minutes, until the rupture of the insulation occurs. The tests for dielectric strength shall be made on a sample of wire 1 foot of which has been immersed for 72 hours in a conducting liquid (salt water, for instance) held in a metal trough. One terminal of the testing circuit is connected to the copper wire and the other to the metal trough.

Tests by the Underwriters are made of the products of the various manufacturers from time to time, and the names of those wires which are acceptable as complying with their standards can be learned from them.

39. Entrance Into Building.—

> 3. There must be drip loops in each wire immediately outside the building.
>
> 4. Wires must enter buildings through separate holes at least 2½ inches apart and slope, at an angle of about 20°, upwards from the outside so that rain cannot gain access to the interior by this path; when practicable, the holes must be bushed with non-absorptive, non-combustible insulating tubes extending through their entire length. Where tubing is not practicable, the wires shall be wrapped with two layers of insulating tape.

40. Size and Location of Holes.—The way to run the wires through the walls of a building is illustrated by Fig. 8. The holes drilled through the building for the reception of the tubing, or *bushings*, as they are commonly called, must be of the proper size to make a binding fit so as to prevent rain from entering between the bushing and the wall into the interior of the building. The size of the holes depends on whether the drop is to be run inside, or whether leading-in wire is to be used for this purpose. Where the drop is brought through the wall, a ⅜-inch hole is necessary; where leading-in wire is used, a ¼-inch hole is sufficient in size. The hole should always be drilled from the inside of the wall when it is

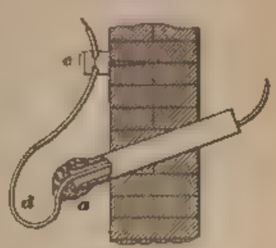


FIG. 8

plastered, because when the direction is reversed the plaster is sure to be broken away. One of the best places to pierce the wall is at the bottom of the window frame, because the hole at the inner surface of the wall will then be shielded by the edge of the wood and be hardly perceptible.

41. Support for Wires.—

5. Wires must be supported on porcelain insulators, so that they will not come in contact with anything other than their designed supports.

6. A separation between wires of at least $2\frac{1}{2}$ inches must be maintained.

In case of crosses, these wires may become a part of a high-voltage circuit, so that care similar to that given high-voltage circuits is needed in placing them. Porcelain bushings at the entrance holes are desirable, and this requirement is only waived under adverse conditions, because the state of the art in this type of wiring makes an absolute requirement inadvisable.

42. Porcelain Fittings.—Fig. 9 is a porcelain **knob cleat** or **split knob** used for supporting single wires. It requires no tie-wire and is provided with four sizes of grooves, so that it will accommodate wires of various thicknesses. They are usually made in two sizes, the larger for wire up to $\frac{5}{8}$ inch in diameter and the smaller for wire up to $\frac{3}{8}$ inch in diameter. Fig. 10 shows the common 4-inch porcelain tube used where wires are run through joists or walls.

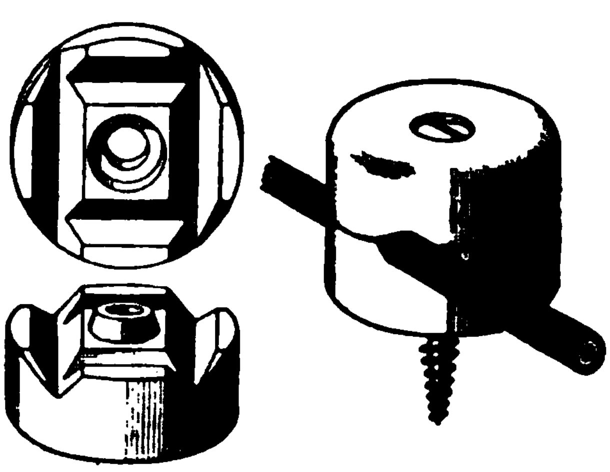


FIG. 9

FIG. 10

Fig. 11 shows a less common style of tube for use where wires are brought through window frames, *a* being the drip loop on the outside. Fig. 12 shows a two-wire porcelain cleat designed to support the wires $2\frac{1}{2}$ inches apart. Many other styles of knobs, tubes, cleats, and insulators are made, but they are much the same in general construction.

43. Kind of Tubing.—Tubing made of porcelain, hard rubber, or some one of the fireproof insulating materials on the market, must be used in the holes. In addition to insulating qualities, the tubing must possess sufficient strength to withstand mechanical shocks, and be impervious to moisture. Porcelain is the best material to use because it is stronger than hard rubber, although not as good an insulator.

The tubing should project about 3 inches on each side of the wall, and the ends should be reamed out in order to remove the sharp edges that might otherwise cut the braid on the wire. Rubber and similar tubing can be cut with a knife, but porcelain cannot be cut or reamed out, hence tubes of the proper length must be selected.

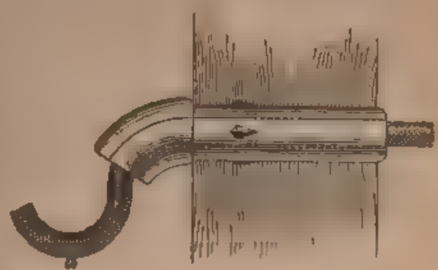


Fig. 11

44. The wire should be supported by a split-knob insulator *c* (see Fig. 8), then bent to form a drip loop *d*, and rubber tape must be wound around the wire and the end of the tube, as shown at *a*, to prevent rain entering through the tube around the wire.

Fig. 12

45. Kind of Wire.—Although the rules call for No. 18 B. & S. or larger, many companies use No. 19 approved rubber-covered and braided wire from the drip loop to the protector. It should be soldered to the drop wire; in fact, all joints should be soldered and taped. Some advise the use of good rubber tape, next to the soldered joint, the whole to be then covered with good friction tape to protect it against injury, the rubber tape keeping out moisture and arresting corrosion.

46. Protector on Outside of Building.—When the protecting device is placed on the outside of the building, the drop wire ends at the protecting device and the line is carried inside by means of a so-called leading-in wire. The way in which this is done is shown in Fig. 13, in which *a* represents the drop wire coming down the outside of the building, being supported on split-knob insulators and entering the iron box *b* containing the protecting device. The ground wire *g* should be supported on split-knob insulators and run as direct as possible to a good ground outside the building. When it is necessary to run the ground wire inside in order to obtain a good ground, the entrance must be made through a separate hole bushed and taped in the manner already described. The two leading-in wires are brought to the entrance point on split-knob insulators, pushed through the bushings, drip loops *e*, *f* are formed, and the wires taped at their entrance to the bushings.

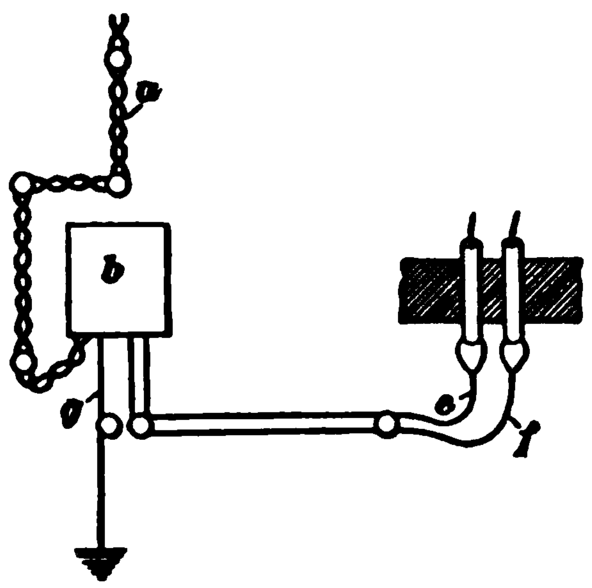


FIG. 13

47. Ground Wire.—

e. The ground wire of the protective device shall be run in accordance with the following requirements:

1. Shall be of copper, and not smaller than No. 18 B. & S. gauge.

2. Must have an approved rubber insulating covering. (See Art. 38.)

3. Must run in as straight a line as possible to a good, permanent ground, to be made by connecting to water or gas pipe, preferably water pipe. If gas pipe is used, the connection, in all cases, must be made between the meter and service pipes. In the absence of other good ground, connection must be made to a metallic plate or bunch of wires buried in permanently moist earth.

In attaching a ground wire to a pipe, it is often difficult to make a thoroughly reliable solder joint. It is better, therefore, where possible, to carefully solder the wire to a

brass plug, which may then be firmly screwed into a pipe fitting. Where such joints are made underground they should be thoroughly painted and taped to prevent corrosion.

Complete directions have already been given for making ground connections.

Triple conductor wires should not be used when the third wire is a ground from the lightning arrester. This ground wire should be run separately, insulated from other wires, pipes, chandeliers, etc., and not put under metallic cleats or staples with the other conductors. Some companies use No. 16 B. & S. rubber-covered and braided wire, and will not allow the use of metal tacks or staples for any part of the wiring.

48. Protector.—

f. The protector to be approved must comply with the following requirements:

1. Must be mounted on non-combustible, non-absorptive insulating bases (such as porcelain, for example), so designed that, when the protector is in place, all parts which may be alive will be thoroughly insulated from the wall to which the protector is attached.

2. Must have the following parts:

A lightning arrester which will operate with a difference of potential between wires of not over 500 volts, and so arranged that the chance of accidental grounding is reduced to a minimum.

A fuse designed to open the circuit in case the wires become crossed with light or power circuits. The fuse must be able to open the circuit without arcing or serious flashing when crossed with any ordinary commercial light or power circuit.

A heat coil, if the sensitiveness of the instrument demands it, which will operate before a sneak current can damage the instrument.

Heat coils are necessary in all circuits normally closed through magnet windings, which cannot indefinitely carry a current of at least 5 amperes. The heat coil is designed to warm up and melt out with a current large enough to endanger the instruments if continued for a long time, but so small that it would not blow the fuses ordinarily found necessary for such instruments.

3. The fuses must be so placed as to protect the arrester and heat coils, and the protector terminals must be plainly marked "line," "instrument," "ground."

If the protectors are arranged for soldered connections, the connections should be soldered by all means, and the protector should not be left without making sure that all the connections are tight, all parts properly adjusted, carbons clean, and the mica properly inserted in place.

WIRING ON TELEPHONE SIDE OF PROTECTOR

49. Insulation of Wires.—

g. Wires on the telephone side of the protector, except where bunched, must be neatly arranged and securely fastened in place in some convenient, workmanlike manner. They must not come nearer than 6 inches to any electric light or power wire in the building unless incased in approved tubing so secured as to prevent its slipping out of place. The tubing may be retained in place by taping both ends.

The wires would ordinarily be insulated, but the kind of insulation is not specified, as the protector is relied on to stop all dangerous currents. Porcelain tubing or approved flexible tubing (such as alphaduct, circular loom, flexduct, or eureka) may be used for incasing wires where required as above.

The National Board of Underwriters regard all telephone wires leading up to the protector as subject to the rules for wires carrying currents at a potential of 600 volts; therefore, the best place for the location of the protector is just before or immediately after entering a building. The wires from the protector to the telephone instruments can then be handled in a much less expensive manner, affording opportunity for better appearance in the finished work.

50. The **kind of wire** to be used on the telephone side of the protector depends on the nature of the work. A better grade of insulation must be used in damp places or places where it is liable to be damp, than in places that are always dry. A wire extensively used for dry places is No. 19 B. & S. rubber-covered and braided wire twisted in pairs.

Several colors are used in making the braid in order to match the various trims (interior woodwork) that are used by builders, such as oak, cherry, mahogany, etc. White braid is also used where the run is to be made along ceilings. The insulation of this wire is not sufficiently thick to withstand moisture, so that this wire should never be run outside of the building.

Probably the best wire for moisture-proof work is a rubber-covered wire, two such insulated wires being twisted together spirally and further protected by one covering of lead. This wire is used extensively by the larger companies and can be drawn into ducts and manholes when necessary, or even laid in water. Where dampness is encountered in a building or where appearance is not a prime requisite, a rubber-covered wire with a saturated waterproof braid should be used, as the plain braid will, in time, develop low insulation and if exposed to the weather will crack. For most work, oak-colored braid, with red marker thread on one conductor, is the best, since in exposed places it is not so conspicuous as darker colors.

The use of wire with jute or other absorbent material in the covering should always be avoided for damp places. For dry places, a cheaper wire can be used, though there is no investment that pays the telephone company better than a good wire well put up.

51. Open or Concealed Wiring. There is some difference of opinion as to which is better, concealed or open work. While open work does not look as well, and is more apt to be tampered with than concealed work, it is, nevertheless, more easy of access. Some contend that concealed wiring, when properly done, is the safest, neatest, and best; and although the amount of labor may sometimes be greater than for exposed work, nevertheless they claim that the expense is justifiable and a distinct economy, unless the surroundings are very crude. Generally speaking, exposed wiring requires better material than concealed work, and the latter, when well done, is permanent and

protected from meddling and trouble. A skilful wireman will make but little, if any, more work out of a concealed job than an exposed one, except in unusual cases where brick and stone walls are encountered.

The tendency at the present time is toward concealed work, and in the most modern buildings, especially office buildings, the surfaces are constructed so as to leave an open space between the outside finished surface and the wall. Then at stated intervals there are removable panels to give access to the interior.

Some prefer the wiring placed in the attic as far as practicable, with the wiring concealed, on the ground that it removes the danger of being cut by burglars and that the appearance is much better.

52. Support for Wires.—The manner of supporting wires on the telephone side of the protector varies greatly and should be governed by conditions. For buildings of mill construction, small wooden cleats, preferably treated previously in some insulating compound, are extensively used. Some recommend porcelain knobs or porcelain cleats, especially for damp places. Saddle staples, or saddle tacks, as they are also called, which are metal staples having a piece of insulating material under the bend, are used in dry places for doing neat work when moldings are not permissible.

The practice of running wires under floors or on ceilings to reach portable telephones should be restricted, for such work usually involves a high maintenance expense and creates dissatisfaction to subscribers, due to frequent disorder. Wherever the wires are run through floors, joists, brick or stone walls, or partitions, use either porcelain tubing or some kind of conduit; circular loom conduit may be used if the partition is dry, and in this case both wires may be run through the same tube.

53. From the point where the wires enter a building, the wires should be run on insulators along the cellar beams to the point where the ascent is to be made. This point should be so selected as to bring the wire up along the walls or

partitions. The proximity to hot- and cold-water pipes, steam pipes, and chimney flues should be avoided, as in such places the wires will soon be ruined by moisture or heat.

When the floor on which the telephone is to be placed has been reached, the wire is lead to the instrument by the shortest possible route consistent with appearances. A good route, for example, is along the surbase, or wainscoting, behind the picture rail or plaster molding at the junction of wall and ceiling. When the picture rail or molding is followed, the run up from the floor must be made along the side of the door jamb or in a similarly concealed place.

When the wire is to be attached to the trim or molding, the color of the braiding must match that of the woodwork, and double-pointed tacks must be used in securing it. These tacks are driven at intervals of about 24 inches, and always over one conductor only of the twisted pair. One tack should never be placed over both conductors, as this practice is sure to result in short circuits.

54. Office buildings in large cities are usually wired with house cables which have one terminal in a cable box placed beside the terminal of the underground cable in the cellar, and one terminal on each of the floors, so that the house wire need only be run from the proper house-cable terminal to the telephone on the same floor. In buildings where there are no house cables, however, the house wire must be run from the underground terminal in the cellar to the telephone. Some buildings are equipped with flues for this purpose, while in others, wanting this provision, there may be elevator shafts that should then be used. In running the wire through the flues above referred to, the start should be made at the floor on which the subscriber's telephone is to be placed, and having brought the coil to the opening, a suitable weight is attached securely to the free end, which is then passed into the flue, and lowered by unwinding the coil, thus allowing the weighted end to descend. An assistant stands in the cellar, grasps the end of the wire as it emerges, and pulls through enough wire to reach the underground

terminal. The cellar run is then properly made, and if any slack then remains it is pulled back up the flue. The wire is then properly run to the telephone and the connection made. By this means if the coil is of sufficient length, the run is made without any splices. When splices are necessary, however, one of the conductors should be cut a little longer—about 2 inches—than the other, so that the joints in the two conductors will not be opposite each other. Thus, should the tape become unwound from any cause, a short circuit will not result. A standard Western Union, or American, splice should be made and soldered, and each conductor wrapped separately with friction tape, and then a layer of the same tape is wound over both wires and joints.

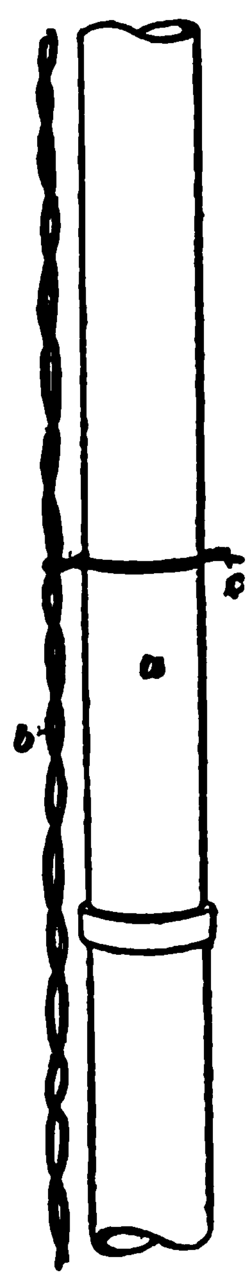


FIG. 14

55. Wiring in Elevator Shaft.—When the wire is to be run down the elevator shaft it can be done in two ways, the selection of which will depend on the conditions to be met with. If the shaft is roomy and free from obstructions and the top is accessible, the best plan is to drop the free end of the wire down in the manner already described for flues from the proper floor until it reaches the cellar. The installer then completes his run in the cellar as before, and the slack is pulled back through the shaft. Where the room in the shaft is restricted, the best plan is to secure permission from the janitor or building superintendent to ride down on top of one of the cars. The wire is carried down in this manner; the trip being made slowly so that the wire may be fastened securely to the side of the shaft as it is brought down. This fastening can be done by surrounding it with a piece of leather, the two ends of which are secured to the wall by screws or nails. If there is in the shaft a pipe other than steam or water, a very good fastening can be obtained, as shown in Fig. 14, by twisting a piece of wire about the line *b* and the pipe *a*, and finally twisting together the ends *c*. All wires

should be protected against fire-doors and ladders and should be attached to permit of no abrasion.

56. Wiring for Extension Telephones.—In branching off from main lines for extension telephones and party lines, these connections offer a constant source of trouble. The splices must be opened frequently in testing for crosses and grounds by repairmen who often do temporary work, intending to go back and make them permanent after they have found the trouble, but who fail to do so. Sooner or later the lines are all cut up and rewiring becomes necessary. A plan that would mitigate this trouble would be to use test blocks at the junction points, but this still admits a cause for trouble from loose contacts, whether screw or soldered connections are made. Good soldering requires some degree of skill, which is not possessed by every repairman.

57. Wires Bunched or Laid in Same Ducts.—

> *h.* Wires connected with outside circuits, where bunched together within any building, or inside wires where laid in conduits or ducts with electric light or power wires, must have fire-resisting coverings, or else must be enclosed in an air-tight tube or duct.
>
> It is feared that if a burnable insulation were used a chance spark might ignite it and cause a serious fire, for many installations contain a large amount of very readily burnable matter.

LINE DISTURBANCES AND TRANSPOSITIONS

DISTURBANCES IN TELEPHONE LINES

CAUSES OF NOISES IN TELEPHONE CIRCUITS

1. The strange noises frequently heard in instruments connected with grounded telephone lines of considerable length may be due to one or more of several causes: The sudden shifting of the earth's magnetic field may induce currents in the line that will cause sounds in the receiver; earth currents, due to differences in potential between the ground plates at the end of the line, may also pass through the telephone instruments, producing the same result; there may be leakage from other lines; a neighboring wire carrying fluctuating currents may have set up about itself a varying magnetic field of force, which field may embrace the telephone line under consideration and cause, by its fluctuations, corresponding alternating currents to flow in the telephone line; and there may be a condenser action between the telephone wire and the neighboring wire by which the latter may induce fluctuating electrostatic charges on the former, which charges, in trying to flow to the ground, will produce currents capable of affecting the receivers.

2. Noises From Natural Phenomena.—The noises due to natural phenomena, such as changes in the earth's magnetic field, or earth currents, are greatly increased during magnetic storms or auroral displays. These noises, which are said by some to increase with the appearance of

sunspots, may be of widely different character; sometimes they resemble the boiling or bubbling of water, sometimes the hissing of steam, and sometimes the twittering of birds. They are frequently so loud and persistent as to render conversation impossible. These noises occur on long grounded lines, and particularly on those running north and south.

3. Noises Due to Leakage.—If the insulation between a telephone line and a neighboring line is very poor, a part of the current from the neighboring line is likely to pass, by leakage, to the telephone line and produce noises in the instruments thereon. This is especially true where both the telephone line and the other line form parts of grounded systems. Electric railways afford the greatest source of trouble in this respect, as they nearly all operate on grounded circuits and carry very heavy currents. The potential of the earth for considerable areas is frequently raised above the normal, due to the grounding of railway circuits, and in such districts the use of grounded telephone lines is well-nigh impossible. The current, after passing through the car to earth from the trolley line, seeks the most direct path back to the power station, and part of it usually passes up through the ground wire at one end of a telephone line, through the telephone instruments, and to ground at the other end, if the two ends of the line are at different potentials. These currents vary in strength according to the position of the car or cars on the line, and are a great annoyance. They can be distinguished from the currents caused by the natural phenomena by the fact that the buzz of the motors on the street cars can be readily distinguished. The commutation of the current on the street-car motors produces fluctuations in the current, thus causing a tone in the receiver that is high or low according to whether the car is running fast or slow.

4. Electromagnetic Induction.—About every wire carrying current, there exists a magnetic field or whirl; and if the strength of the current flowing in a wire is varying, this field of force will contract or expand according to whether the current strength is decreasing or increasing.

If a telephone wire lies close enough to a wire carrying such a current to be within its field of force, it will be cut by the magnetic lines of force as they contract or expand; and this, by the well-known laws of electromagnetic induction, will set up electromotive forces in the telephone wire that, in turn, will cause currents to flow through it and the receivers connected with it.

This principle is illustrated in Fig. 1, in which $A B$ is the disturbing wire carrying, we will say, an alternating current, and $C D$ a grounded telephone line running parallel with $A B$ and having two receivers R, R' connected in its circuit. If at any moment the current in the wire $A B$ is flowing as indicated by the arrow, that is, from B to A, and is increasing, a magnetic whirl will be set up about it in the direction

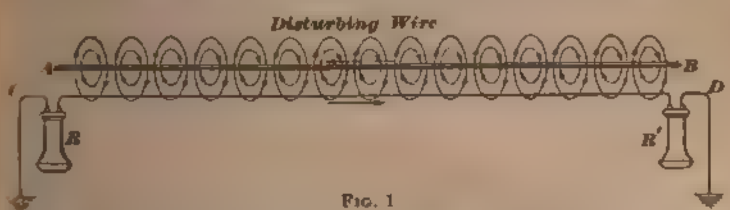


FIG. 1

indicated by the curved arrows. This whirl will be expanding while the current is increasing, and in so doing, more and more lines will cut the wire $C D$. This will induce in the telephone line a current flowing in the opposite direction to that in the disturbing wire, that is, from A to B, as shown by the lower arrow. When the current in the disturbing wire begins to decrease, the lines of force about it will contract, thus inducing in the telephone line a current in the same direction as that in the disturbing wire. In general, it may be said that, while the current in the disturbing wire is increasing, the induced current in the telephone wire will be in the opposite direction; but when the current in the disturbing wire is decreasing, the induced current in the telephone wire will be in the same direction.

5. Electrostatic Induction.—Another and more important kind of induction between neighboring wires is

due to the electrostatic action between them. This may best be explained by reference to Fig. 2, in which AB is the disturbing wire and CD a telephone wire having two receivers R, R', as before. If the disturbing wire is carrying alternating currents, it will receive alternate, positive, and negative charges. Assume that, at a certain time, the charge on a disturbing wire is positive, as indicated in Fig. 2. This positive charge will call forth two charges on the telephone line, one of which being negative will be held by the positive charge on the disturbing wire, while the other being positive will be repelled and will pass to ground. In order to pass to ground, it must pass through the receiving instruments at each end and will therefore produce sounds in them. The direction of the current at this

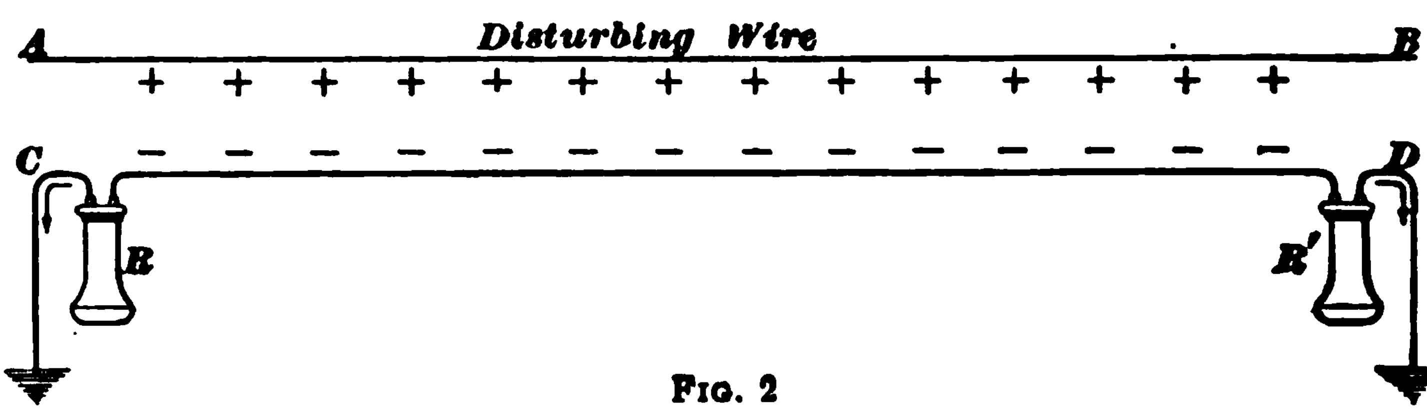


FIG. 2

instant is indicated by the arrows at C, D. If the positive charge on the disturbing wire gradually increases from zero to a maximum, the negative charge on a telephone wire will gradually increase, thus allowing more and more of the positive charge to flow to ground. When the positive charge on the disturbing wire begins to decrease, the negative charge on the telephone wire will also decrease, and therefore positive electricity from the ground will flow up through the receivers to neutralize it. As the charge on the disturbing wire changes from plus to minus, the bound charge on the telephone wire will change from minus to plus, and the action just described will be reversed.

6. Where the disturbing wire is a portion of a circuit carrying current for lighting or power purposes, the induced current, whether electromagnetic or electrostatic, or both, produces a hum corresponding in pitch to the number of

fluctuations per second in the current flowing in the circuit. The tone produced is not unlike that of an alternating-current transformer, and may be readily distinguished from any other line disturbances. Alternating-current circuits, of course, produce far greater inductive effects than direct-current circuits, but even the latter cause much trouble, owing to the fact that the commutation of the direct currents is never such as to produce a perfectly smooth current. Sometimes the disturbing wire is a telegraph wire, and induction from this source may be readily distinguished, due to the fact that the telegraph signals are repeated in the telephone receivers.

7. **Minimum Disturbing Current.**—Experiments that have been made to determine the permissible current in a telephone receiver at commercial frequencies that will not interfere with telephonic transmission show that a current of approximately .000005 ampere is permissible. This will vary slightly with the frequency of the disturbing current, its wave form, and the sensitiveness of the receiver employed. However, this is a safe value in general practice. It is obvious that receivers of low sensitiveness and transmitters of maximum power will give the most satisfactory service where there is trouble from induction.

CROSS-TALK

8. Induction may take place between two or more adjacent telephone lines to such a great extent that a conversation carried on over one line may be heard on the others, even though the lines are entirely and perfectly insulated from each other. This phenomenon of overhearing conversation on a circuit other than that over which it is originally conducted is called **cross-talk.** It produces much confusion when one or more subscribers are talking at the same time, and its elimination is a very important problem in practical telephony.

It was believed by some that cross-talk was due entirely to electromagnetic induction. Mr. John J. Carty, however, conducted a series of experiments that proved conclusively

that it is almost entirely attributable to electrostatic induction—to so great an extent, in fact, that electromagnetic induction may, on ordinary telephone circuits, be entirely neglected. As the experiments by which he demonstrated this are very interesting, several of them will be considered.

9. Carty's Experiments on Cross-Talk.—In Fig. 3, *A B* is the disturbing wire and *C D* the wire on which the inductive action is to be studied. These two wires are each 200 feet long and $\frac{1}{8}$ inch apart, and well insulated from each other. The line *A B* is open at one end, the other end being grounded through the secondary winding of an induction coil. The primary winding is connected in circuit

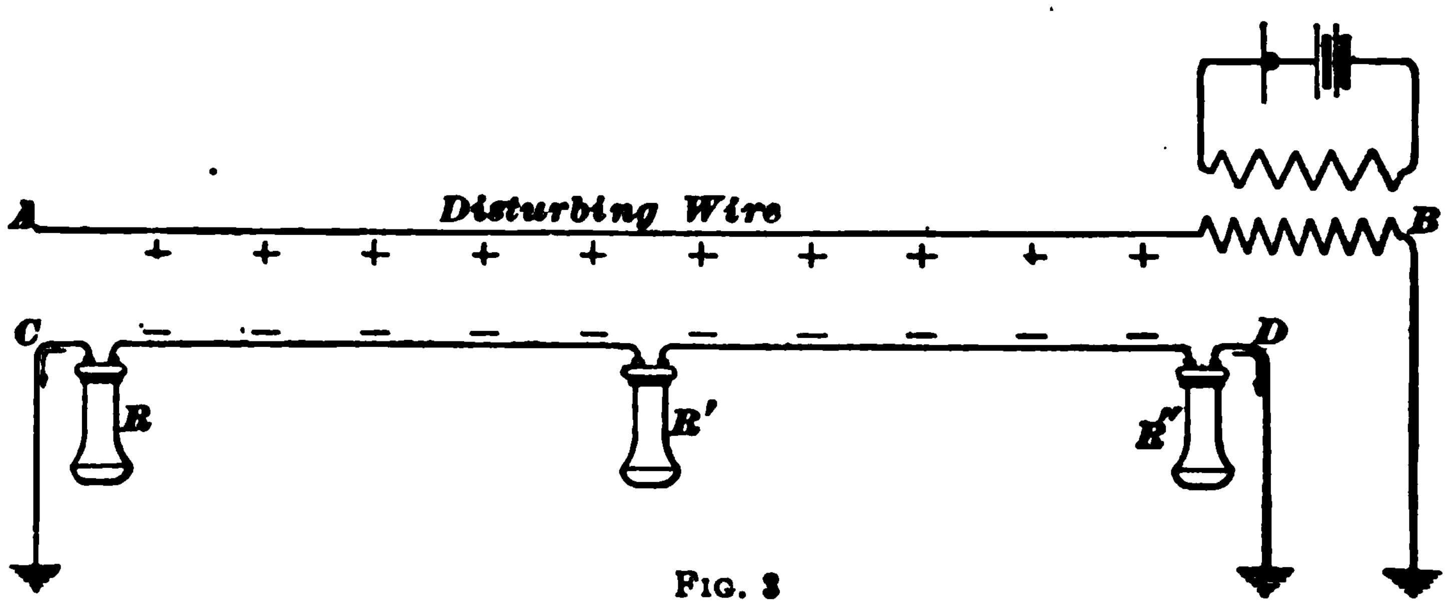


FIG. 3

with a transmitter and a battery, and in front of the transmitter is mounted a tuning fork, which by its continuous vibration causes the transmitter to produce in the primary current undulations which in their turn impress an alternating electromotive force on the line wire *A B*. Inasmuch as the wire *A B* is open at one end, the conditions are more favorable for electrostatic action than for electromagnetic, because the only current that can actually flow in the line *A B* is that required to charge it to the potential of the impressed electromotive force. If at the moment considered a positive charge is formed on the disturbing wire, a negative charge will be held on the line *C D*, as already described. As the charge on *A B* changes to negative, the negative charge on *C D* is released and is replaced by a positive charge. These charges on the wire *C D* will pass to ground through the

path of least resistance, that is, from the center to the ground connection at each end of the line. This means that at any instant the current flowing in the line CD will be either toward or from its center point; and if a receiver R' is placed in the line at that point, there should be no sound in it, while the receivers R and R'' will each be actuated by the currents passing through them to or from the ground. This Mr. Carty found to be the case. He also reasoned that, if the currents in the line CD were always flowing to or from its center point, it should produce no effect on them if the line were opened at that point. An experiment proved this supposition to be true. By grounding the point A of the line AB through a considerable resistance, he found that the same results held true; and that, although a complete circuit was afforded for the alternating currents generated in the secondary coil in the line AB, the induction was still electrostatic. If electromagnetic induction had been present to any considerable extent, noises would have been heard in all three of the receivers, for at any instant the current would be in the same direction through all three of them. Moreover, opening the wire CD at its center point would preclude the flow of current through the wire from one end to the other, and therefore render electromagnetic induction impossible.

10. As another experiment, Mr. Carty arranged the circuits as shown in Fig. 4. In this, a key K was provided, by means of which the receiver R at one end of the line could be short-circuited. With this key open, the usual tones, due to the induced current, were heard in both receivers. With the key closed, it was found that the noise in each of the receivers ceased. This proved conclusively that the induction was electrostatic, for the key, when closed, provided a short circuit through which all the charges could pass to ground. The current would not pass through R because the key short-circuited it, nor through R' because the wire and short circuit around R offered a path to earth of much less resistance than that of the receiver R'. If the induced electromotive force had been caused by electromagnetic

instead of electrostatic induction, the noises in the receiver *R'* would have increased, for the resistance through which the current induced in the wire *A B* had to flow would have been diminished, rendering the current correspondingly greater.

Mr. A. E. Kennelly afterwards mathematically proved that the electrostatic induction on such a circuit would be about

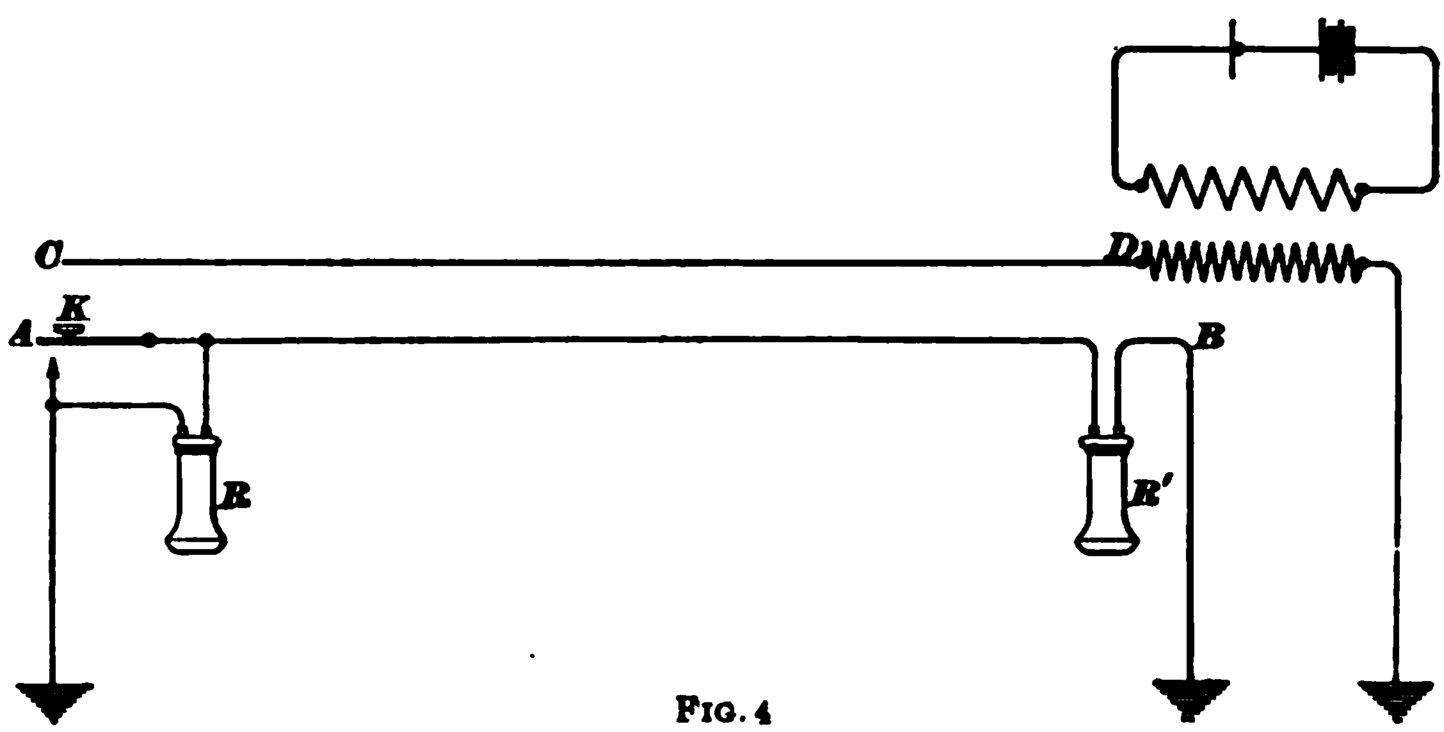


FIG. 4

twenty times as great as the electromagnetic, which bears out well the results of Mr. Carty's experiments.

11. Overcoming Cross-Talk.—The obliteration of cross-talk was at one time the chief problem to be solved in commercial telephony, but it has been successfully and completely solved by the use of properly designed metallic circuits instead of grounded lines. When a complete metallic circuit is used, no cross-talk or other induction is developed if the disturbing wire is at equal distances from each telephone wire. This is explained by the aid of Fig. 5, where the two halves of a complete metallic circuit are shown at *a* and *a'*, *r* and *r'* representing the coils of telephone instruments placed at opposite ends of the circuit, and *c d* representing a disturbing wire placed in such a position that all its points will be at the same distance from *a* that they are from *a'*. If alternating charges are produced on *c d*, either by a telephone or by any other source, alternating charges with opposite signs to these will be produced on *a* and *a'*. When a negative charge is produced on *c d*, a

positive charge is produced on the sides of the wires a, a' that are nearest to $c\,d$, while on the other sides, negative charges are produced. As the metallic circuit is not grounded, this negative charge cannot flow to earth, and therefore flows as far as possible from the negative charge on the wire $c\,d$, which is at the opposite side of the wires a, a', as shown. As the charge on $c\,d$ reaches zero, a current will flow across each wire, but not lengthwise, for the potential is exactly balanced on each wire a, a'. The charges of opposite sign

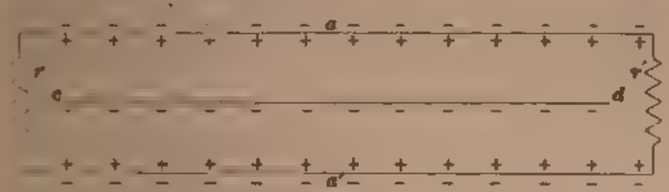


FIG 5

simply come together and neutralize each other across the wires. There is no tendency for the free negative charge on a to flow away, as in the case of the grounded wire, because there is an equal free negative charge everywhere on the circuit. If, however, the wire $c\,d$ is nearer a than a', the free negative charge on a will be greater than that on a', and some current will flow. In this case, the line is said to be out of balance, and some cross-talk or induction will take place. The arrangement of circuits shown in Fig. 5 is an ideal one that can seldom be attained in practice.

12. Fig. 6 shows a case where both wires of a telephone circuit are on the same side of the disturbing wire $C\,D$. The wire $A\,B$ is quite close to $C\,D$, but the wire $E\,F$ is so much farther off that it is practically beyond the variable field produced by $C\,D$. When $C\,D$ is charged negatively, $A\,B$ will be charged positively, the free negative charge in the telephone circuit flowing as far off as it can, that is, into the wire $E\,F$. In doing so, all the charges on the wire $A\,B$ to the right and left of the receiver R_1, which is at the middle of the resistance of the wire $A\,B$, will flow through the end receivers R_2 and R, respectively, to the receiver R_1; that is,

the charge divides at R_1 and flows to the right and to the left from that point.

When the charge on CD becomes zero, this action is reversed and the positive charge on AB divides at R_1, flowing back through the two end receivers R, R_2 to meet and

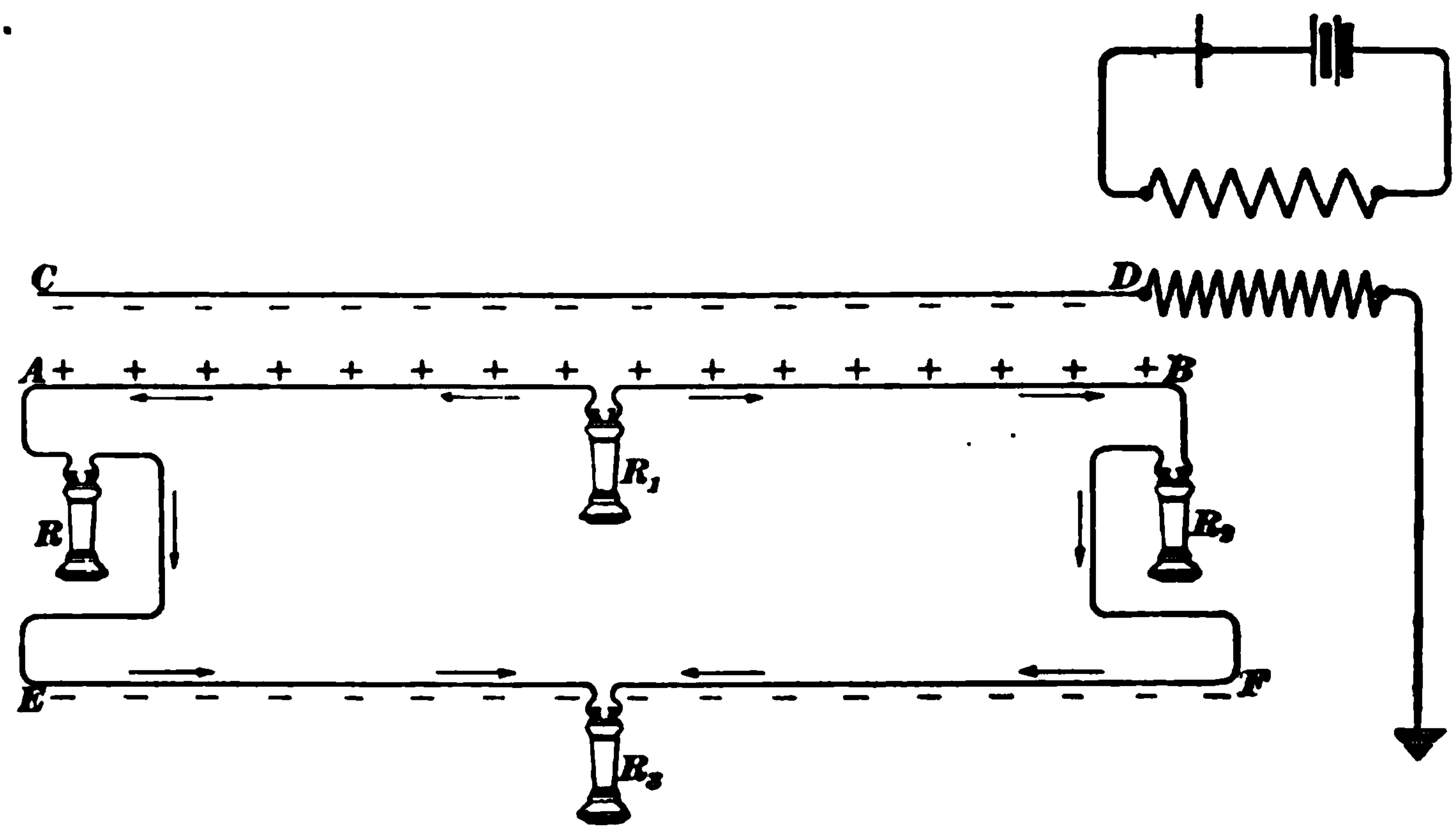


FIG. 6

neutralize the negative charge on EF, as shown by the arrows. Thus, no charge in either case flows through the receivers R_1, R_3, but half the total charge in both cases does flow through each end receiver R, R_2. Consequently, sound is produced in both R and R_2, but none in R_1 or R_3.

13. If only four wires were to be considered, those forming the sides of two separate metallic circuits, the arrangement to effect a perfect neutralization between the two circuits would be that shown in Fig. 7. In this, a and a' are the cross-sections of the wire of one circuit and b and b' those of the other. This arrangement could be readily accomplished if two circuits only were to be used, but would be unavailable for more than two, and therefore it is seldom if ever used. The method of **transposition**, the theory of which is illustrated in succeeding figures, is extensively used in this country, and has given the best of satisfaction on the longest lines in the world.

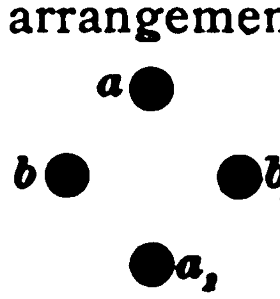


FIG. 7

TRANSPOSITIONS

14. Theory of Transposition.—In Fig. 8, the disturbing wire *c d* is located at one side of the metallic circuit *a*, *a'*; and the resistances *r*, *r'* at each end of the metallic circuit represent the coils of the subscribers' instruments. It is obvious that, if the two sides of the metallic circuit did not change places at the center point on the line, there would be a chance for both electromagnetic and electrostatic induction, because the side of the metallic circuit nearer to the disturbing wire would be subject to greater inductive action than the side farther away. By making a central transposition, however, the liability to cross-talk is greatly

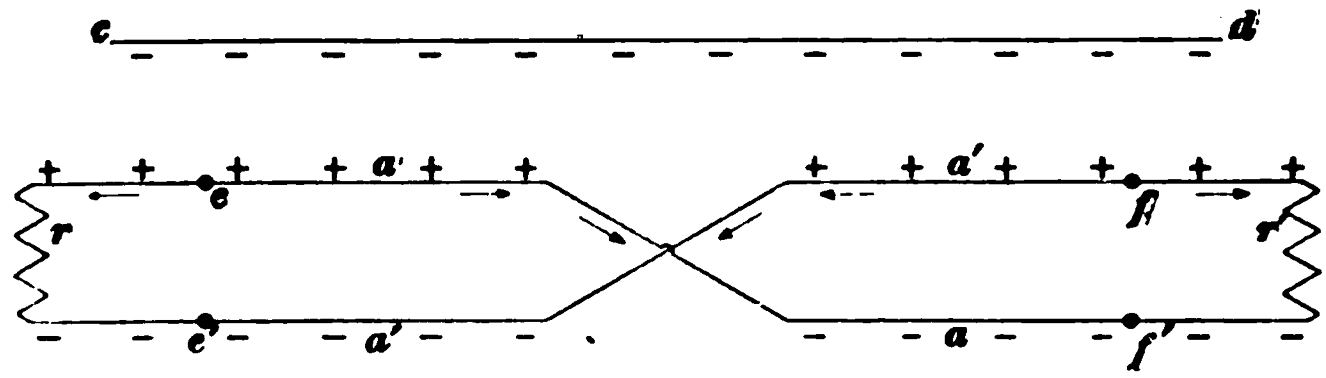


Fig. 8

lessened. Electromagnetic induction is entirely eliminated, for the average distance of the wire *a* from the disturbing wire is the same as the average distance of the wire *a'* from the disturbing wire.

15. While the transposition will greatly reduce the sounds in the receivers, due to electrostatic induction, it will not completely eliminate them. When *c d* receives a negative charge, as in the figure, a positive charge is induced on the nearer portions of *a*, *a'*, while a negative charge is repelled to the more remote portions of the same wires. As the negative charge on the wire *c d* reaches zero, currents flow from the nearer portions of *a*, *a'* to the more remote portions, and two paths are afforded for the currents thus flowing from each section of the wire. Thus, the positive

charge on the left-hand portion of the wire *a* will divide, part flowing through the receiver coil *r* and part through the cross or transposition wire, in order to reach the sides of the metallic circuit that are farthest from the disturbing wire. If the resistance through the transposition wire were the same as that through the receiver, a neutral point *e* would be found in the center of the left-hand portion of the wire *a* from or toward which all induced currents would flow. As it is, however, the resistance through the receiver *r* is much higher than that through the transposition wire, and therefore most of the current is forced through the latter path, thus moving the neutral point *e* toward the end of the line. Four neutral points *e*, *e'* and *f*, *f'* may be found on the line, as shown, and there would be no sounds in the receivers if connected in the circuits at these points. On a line of considerable length, one transposition is not enough to give complete immunity from cross-talk, because the resistance from the neutral point through the transposition is sufficient to force a considerable portion of the induced charge through the receivers at the ends. It is customary, therefore, on very long lines, to make transpositions about once every quarter or every half mile, which is usually sufficient to give complete freedom from disturbing noises, even on the longest lines in use.

TRANSPOSITIONS TO ELIMINATE CROSS-TALK

16. Scheme of Transpositions.—Where many wires are used, the transpositions must be carefully planned. When two circuits only are considered, transpositions in only one will serve to prevent cross-talk between them, although, of course, it will not serve to prevent outside disturbances from affecting the circuit that is not transposed. If more than two circuits are used, it will not be sufficient to transpose them all in the same manner; neither will it do to leave one of them untransposed and to transpose the others in the same manner. For example, in Fig. 9, the circuit *a* is not transposed at all, while the circuits *b* and *c* are transposed at their center points. If the line is a short one, there will be no

appreciable cross-talk between *a* and *b*, as we have seen in connection with Fig. 8; for the same reason there will be no cross-talk between *a* and *c*; but between *b* and *c* there will be cross-talk, as the average distances of the two wires of *c* from either wire of *b* are not equal to each other. In fact, the circuits *b* and *c* bear almost the same relation to each

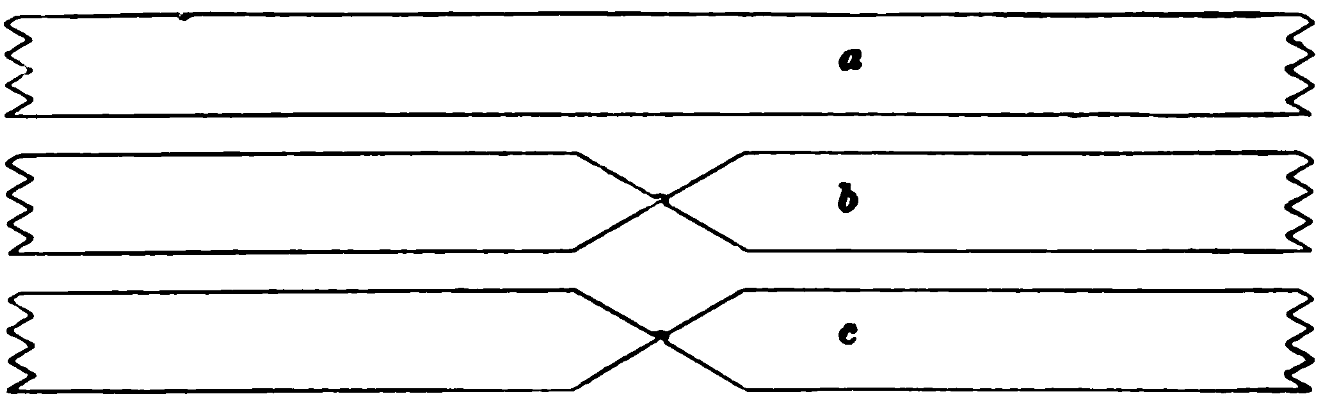


FIG. 9

other as if they were not transposed at all. To overcome this difficulty, twice as many transpositions must be made in the third circuit as there are in the second, as shown in Fig. 10.

17. Standard and Special Transposition Sections. In the transposition* of telephone lines for the elimination of mutual disturbances between themselves, it is necessary to adopt a certain standard length of section within which

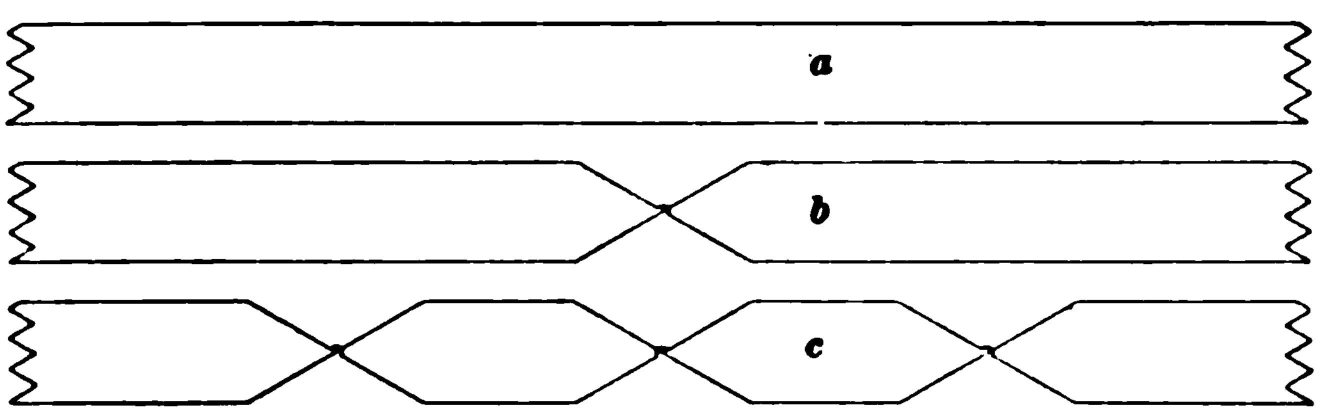


FIG. 10

all the wires shall be transposed, and within which all of the mutual disturbances are made to vanish. The procedure of transposing is to take a standard section, starting from one

*For some of the following information relating to transpositions for the elimination of cross-talk and disturbances from power and lighting circuits, credit is due Frank F. Fowle through his papers presented to the American Institute of Electrical Engineers (October, 1904) and other societies.

end of the line, and applying it consecutively until next to the last section is reached, or until a section is reached before which some radical change is made in the line. A radical change may be the junction with another line, or the removal from the line, or the terminal, of one or more pairs of wires. If, after applying the greatest number of standard sections, there is a remainder less than half the length of a standard section, add the remaining distance to the preceding section, which then constitutes a special section; but it is transposed like a standard section with longer distances between the transpositions, that is, with longer lengths of exposure. If the remainder is greater than half the length of a standard section, it is made a special section and transposed like a standard section, the lengths of exposure being shorter than in a standard section. The first pair in a standard section may have no transpositions, the second pair one transposition, the third pair two transpositions, and so on, each pair having one more transposition than the preceding.

18. Types of Transpositions.—It is necessary to devise different types of transposed circuits, no two transposed alike, in order to treat the cases occurring in practice. The manner of doing this is shown in Fig. 11. The derivation of the types is simple; the first two are obvious. The third is obtained by adding, or combining, the first two. The fourth is obtained by doubling the number of transpositions in the second and the fifth by combining the first and fourth, etc., as indicated under the word *derivation* on the right of the figure.

19. The treatment of induction between telephone circuits has been by empirical rule rather than theory. It has been determined by experiment, with receivers of a given sensitiveness and transmitters of a given power, how frequently two adjacent circuits should be transposed in order to eliminate cross-talk. Using 2-mile sections transposed at the center, the cross-talk is distinguishable with transmission sufficiently powerful for 1,000-mile service; $\frac{1}{2}$-mile or $\frac{1}{4}$-mile sections transposed at the center are satisfactory; this results

in a minimum transposition spacing of ¼ mile. The existence of cable at each end of the line, in any considerable length, will reduce the cross-talk.

20. Length of Standard Transposition Section.—A convenient distance to take for the length of a standard section, where the number of circuits does not exceed twenty or thirty, is between 5 and 10 miles. The point is

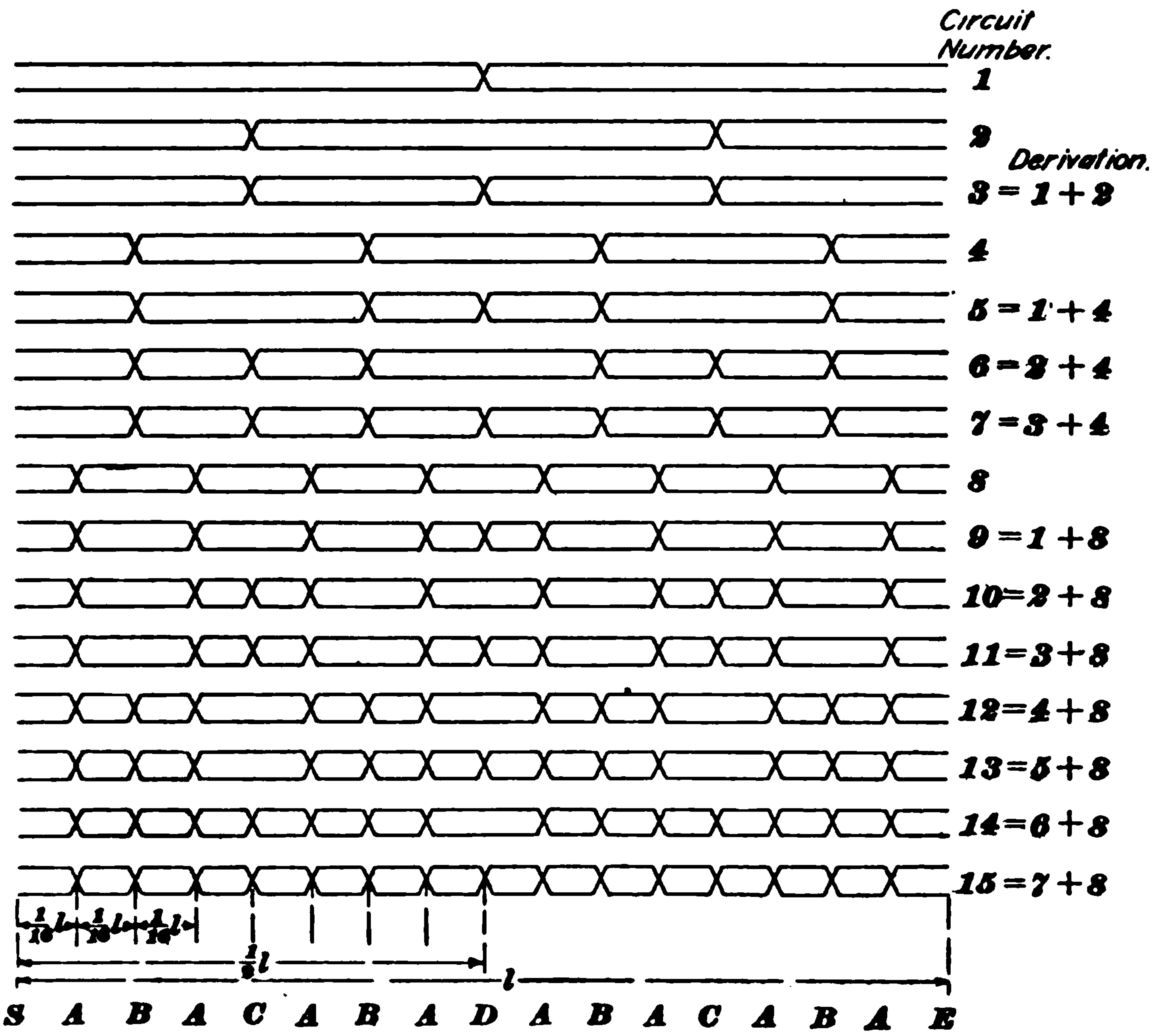


FIG. 11

to adopt a length, in connection with the standard line span in use, such that the transpositions will fall at convenient places and that the shortest length between two consecutive transpositions will be an integral multiple of the standard distance between poles. The best standard of exposure between two adjacent horizontal circuits on a ten-pin cross-arm is one-fourth of a mile between transpositions.

If two such adjacent circuits are transposed one-fourth

of a mile from one of the terminals, and then at each consecutive half-mile, to the distant terminal, it will be found that, with the standard of transmission now in general use, the cross-talk will be entirely negligible, and under normal conditions absolutely unapparent.

The general rule, in applying a standard unit section to any line, is to make any discontinuity in the line the junction of two contiguous sections. A **discontinuity** is constituted by the junction with the line of other lines coming to the main line or leaving it, and it is also a point at which all or any of the lines enter an intermediate or terminal office.

21. The choice of a convenient length l is rather important. An 8-mile section has been extensively used, but it is

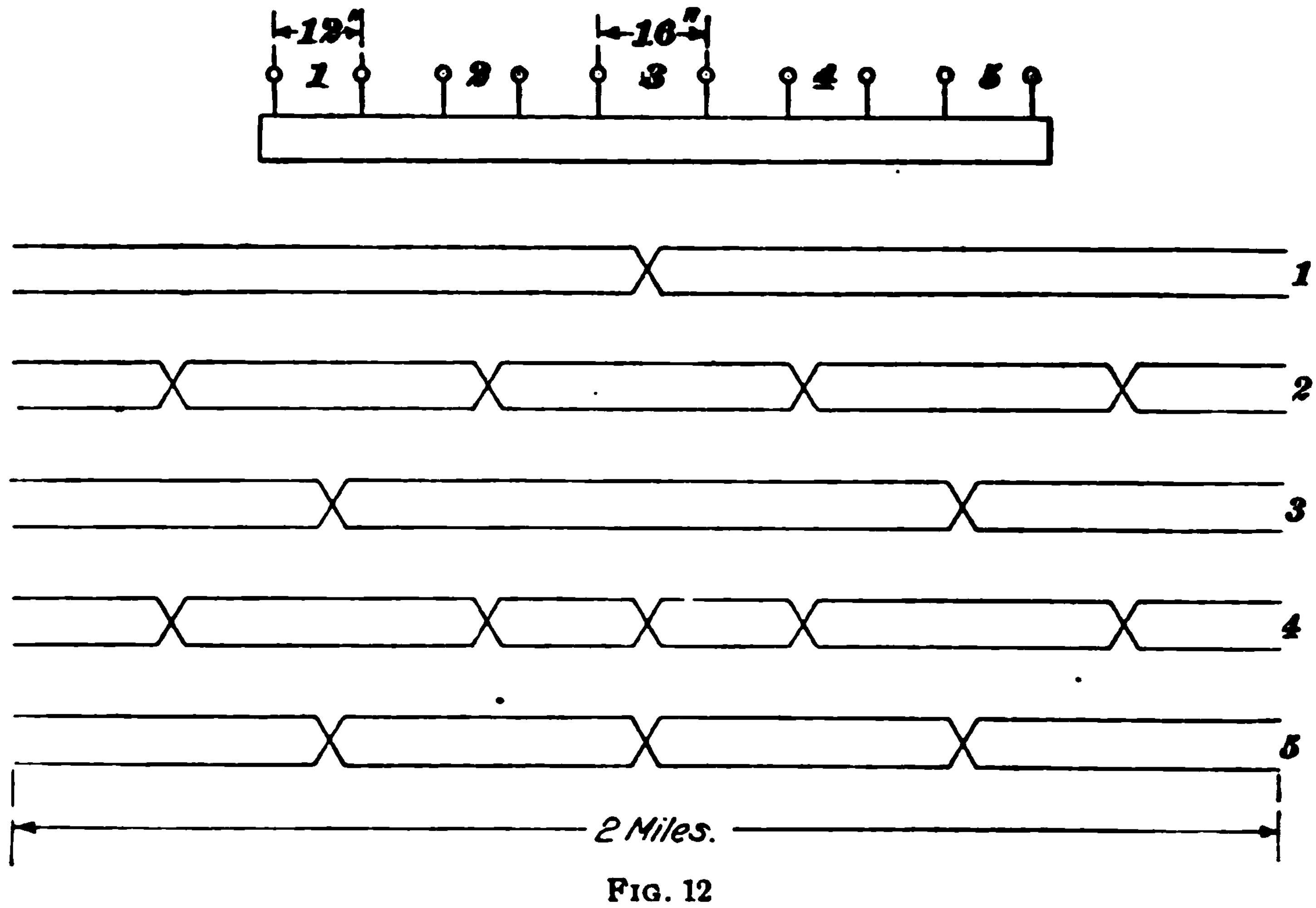


FIG. 12

rather long; 4 miles is a much more convenient length. If there are only a few circuits, a 2-mile section may be used. A case of this kind is a ten-wire line, on a single cross-arm, as shown in Fig. 12. The fifteen types shown in Fig. 11 will be sufficient for a forty-wire line, because there will be certain exposures requiring transposition only at long intervals, and these extra transpositions may be located at the junction poles between sections.

22. Long-distance lines have been successfully transposed according to the following system, which requires thirty-two transposition poles for a complete section. The length of a standard transposition section is 41,600 feet (nearly 8 miles) and the distance between transposition poles in a standard transposition section is 1,300 feet, or nearly $\frac{1}{4}$ mile.

When building from one end of the line only, proceed as follows in locating transposition poles: Starting from the first open-wire fixture, measure along the line standard transposition sections of 41,600 feet in length. If the line is not exactly divisible into 41,600-foot sections, there will remain, between the end of the last standard transposition section and the end of the line, a distance less than 41,600 feet in length; if this distance is greater than 21,000 feet, treat it as a special transposition section; if it is less than 21,000 feet, add it to the last 41,600-foot section, and treat the resulting section as a special transposition section.

When building from each end toward the center of the line, proceed as follows in locating transposition poles: Starting from the first open-wire fixture at each end, measure off toward the center of the line, transposition sections of 41,600 feet in length. If, at the meeting point, the distance between the last transposition section measured from each end is less than 41,600 feet, and greater than 21,000 feet, treat this distance as a special transposition section; if it is less than 21,000 feet, add it to one of the adjacent 41,600-foot sections, and treat the resulting section as a special transposition section.

Special transposition sections should contain thirty-two transposition poles; while the distance between transposition poles in a special transposition section should be $\frac{1}{32}$ of the length of the special transposition section. Special transposition sections are transposed exactly like standard transposition sections. The only difference between the special and standard transposition sections is the length of the section and the distance between the transposition poles. It is important, especially in special transposition sections, that all

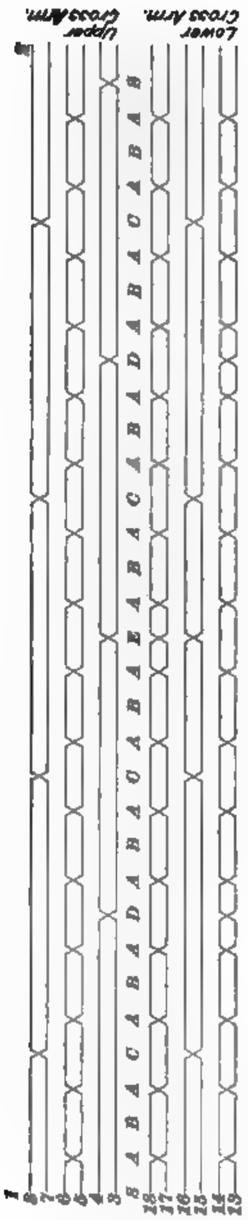


FIG. 13

transposition poles be placed as near as possible to their measured points.

23. Transposition poles (see Figs. 13 and 14) are marked *A*, *B*, *C*, *D*, *E*, or *S*. Measured from the first open-wire fixture, which may be considered the first *S* pole, where, however, no transpositions are required, the distance to the first *A* pole is 1,300 feet; to the first *B* pole, 2,600 feet; to the first *C* pole, 5,200 feet; to the first *D* pole, 10,400 feet; to the first *E* pole, 20,800 feet; to the second *S* pole, 41,600 feet. Counting from the first *A* pole, every alternate transposition pole is an *A* pole. Counting from the first *B* pole, every fourth transposition pole is a *B* pole. Counting from the first *C* pole, every eighth transposition pole is a *C* pole. Counting from the first *D* pole, every sixteenth transposition pole is a *D* pole. Counting from the first *E* pole, every thirty-second transposition pole is an *E* pole. Counting from the first open-wire fixture every thirty-second transposition pole is an *S* pole.

24. The system of transpositions shown in Fig. 13 is suitable for six circuits, that is, twelve wires on two cross-arms; and that shown in Fig. 14 for twenty or more circuits, that is, forty or more wires on four or more cross-arms. On ten-pin arms, the wires are numbered as

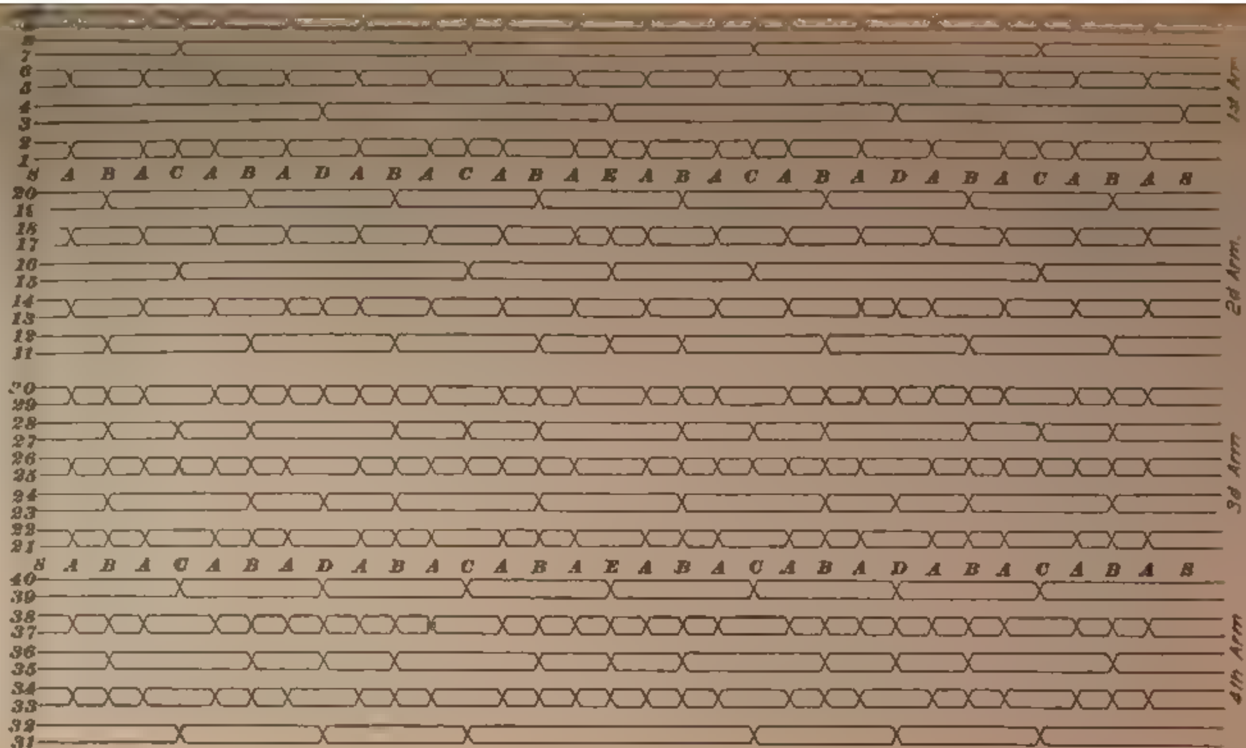

1st Arm
2d Arm.
3d Arm
4th Arm
S A B A C A B A D A B A C A B A E A B A C A B A D A B A C A B A S

Fig 14

shown in Fig. 14. On eight-pin arms, the wires on the first arm are numbered *1–2–3–4–7–8–9–10*, and on the second arm *11–12–13–14–17–18–19–20*, the numbers on each side of the pole on a ten-pin arm being omitted. On six-pin arms, the wires are numbered as shown in Fig. 13; the two outside wires on each end of a ten-pin arm are omitted. On four-pin arms, the wires on the first arm are numbered *3–4–7–8*, on the second arm *13–14–17–18*; the middle and outside pair on each end of a ten-pin arm are omitted. Brackets are numbered *5* and *6*. If there are more than two arms on a pole line, follow the same method of numbering. For instance, if there are three four-pin arms, number the wires on the third arm *23–24–27–28* (see third arm in Fig. 14). The wires, when numbered as shown in Figs. 13 and 14, are transposed as follows:

TABLE I

Top Arm		Second Arm		Third Arm		Fourth Arm	
Wires	on Poles	Wires	on Poles	Wires	on Poles	Wires	on Poles
1, 2	*A–C–E*	*11, 12*	*B–E*	*21, 22*	*A–B*	*31, 32*	*C–D*
3, 4	*D–E–S*	*13, 14*	*A–D*	*23, 24*	*B–D*	*33, 34*	*A–B–E*
5, 6	*A*	*15, 16*	*C–E*	*25, 26*	*A–B–C*	*35, 36*	*B–D–E*
7, 8	*C*	*17, 18*	*A–E*	*27, 28*	*B–C*	*37, 38*	*A–B–D–E*
9, 10	*A–C*	*19, 20*	*B*	*29, 30*	*A–B–D*	*39, 40*	*C–D–E*

The fifth, sixth, seventh, and eighth cross-arms are transposed like the first, second, third, and fourth cross-arms, respectively, except that at the first, third, fifth, seventh, and other odd *S* poles all pairs on the fifth, sixth, seventh, and eighth cross-arms, excepting *3* and *4*, will be transposed.

25. In Fig. 15 is shown the scheme of transposition on the New York-Chicago line, the poles on which transposition are made being 1,300 feet apart. The same scheme of transposition is used on every other set of cross-arms; thus, the cross-arms at the top of the poles will be arranged as shown in the upper part of Fig. 15; the next set will be arranged as shown in the lower portion of that figure; the

third will be like the first, and the fourth like the second, and so on throughout the entire number of sets of cross-arms.

In telephone cables, the transposition of two wires forming a pair is accomplished by twisting the two wires spirally about each other, a complete twist being accomplished every few inches. The pairs are put in layers, each layer forming a long spiral around the preceding layer in the opposite direction. Thus, the two wires in no two pairs have the same relation to each other throughout the cable; in other

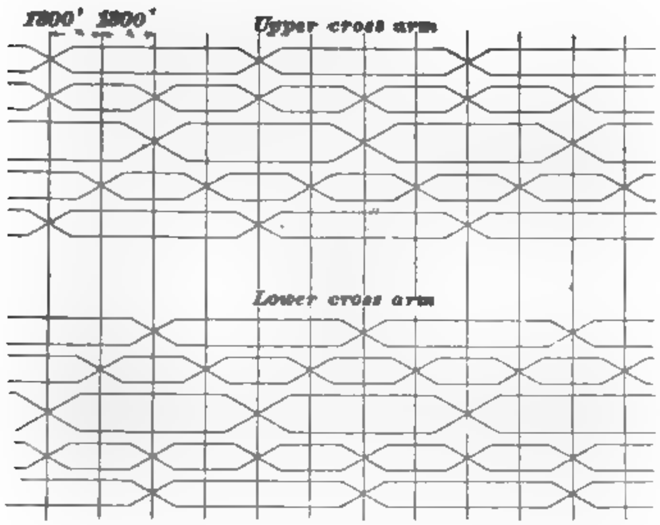


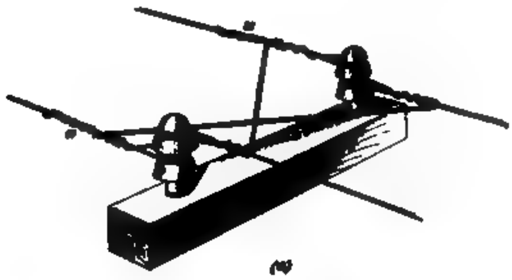
FIG. 15

words, the two wires of one pair are each at the same average distance from each of the two wires of any other pair in the cable.

METHODS OF MAKING TRANSPOSITIONS

26. A common way of making a transposition where ordinary twisted joints are used is shown in Fig. 16 (*a*), where the wires are both on the same side of the pole, and in Fig. 16 (*b*), where the pole comes between the two wires. A better way to make a transposition is shown in Fig. 17. The transpositions so far shown are used mostly for iron

wires, in which case the joints x should be well soldered. Where the joints at transpositions are made with McIntire



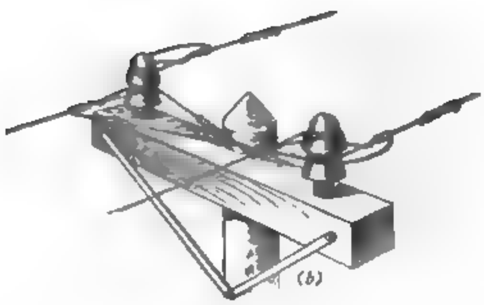


FIG. 16

or other sleeves, which are generally required for line circuits of hard-drawn copper wire, the transpositions are

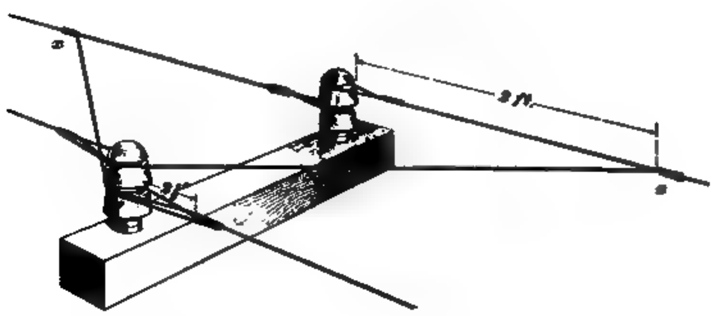
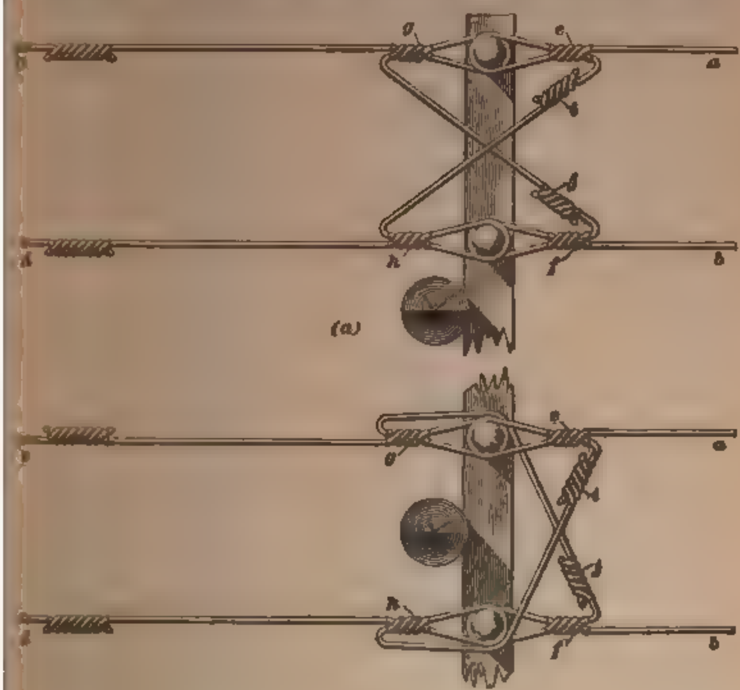


FIG. 17

usually made as shown in Fig. 18 (a), where both wires are on the same side of the pole, and in Fig. 18 (b), where the

pole comes between the wires. Whole sleeves are used at *c*, *d*, and half sleeves at *e*, *f*, *g*, *h*, *i*, *j*. Sleeves and the way to make joints with them will be explained elsewhere. In any case, the cross-over wires should either be insulated



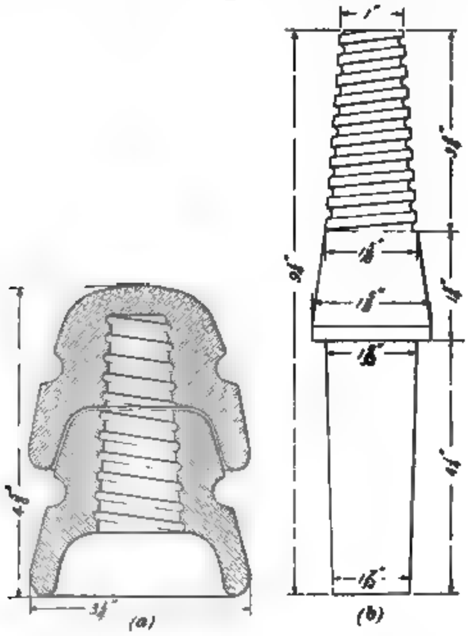
(b)

FIG. 18

or else so bent as to avoid the possibility of crosses, the latter plan being the more common.

27. Transposition Insulator and Pin.—When transpositions are made in this manner, an insulator with two grooves around it must be used. A **transposition insulator** and its pin is shown in Fig. 19 (*a*) and (*b*), respectively. The insulator (*a*) is made in two separate pieces, each having a groove around it. The pin screws through the lower one into the upper one. This is sometimes known as the **Hibbard transposition insulator.**

28. Cutting In a Transposition.—Transpositions made with sleeves are usually cut in about as follows: Cut the wires *a*, *b*, Fig. 18, on the pole side of the cross-arm 20 inches from the cross-arm, slip half sleeves *e*, *f* on each wire *a*, *b* and dead end these wires, leaving the ends projecting from the sleeves. When twisting the sleeve at a dead end hold the stationary clamp next the insulator, so that the twist will be made in the long section. Then cut in 6 feet of



(a) (b)

Fig. 19

slack wire by means of a whole sleeve on each of the other wires *c*, *d*; slip half sleeves *g*, *h* on the slack ends; pull up the wires and dead end them, leaving the long ends on after the dead ends have been made; connect these long ends with the opposite short ends by half sleeves *i*, *j*. Some advise using test connectors about every 5 miles in place of the half sleeves *i*, *j*. At such connectors the line circuit can be readily opened to facilitate testing. Wires *a*, *d* are dead ended in top grooves of the insulators and *b*, *c* in the bottom

grooves. The wires crossing from one side to the other should be placed in such a manner that they will not become crossed. All half sleeves are to be given one and one-half twists, and whole sleeves three complete twists.

When the pole wires are to be transposed, the long ends are to be brought around the insulator on the side away from the pole, so that the complete transposition will be made on the cross-arm side of the pole, as shown in Fig. 18 (*b*).

29. There exists a disadvantage in connection with the method of making transpositions, just described, which is particularly apparent where telegraph and telephone services are given simultaneously on the same line. To explain this point fully, just a word must be said on the two methods of giving telegraph service on a telephone line. Telegraph service is given either by the **simplex method,** or the

FIG. 20

composite method. By the simplex method, both conductors of the telephone circuit are taken for the metallic side of one telegraph circuit, the earth being used as a return. In this case, any change in the relative positions of the two conductors does not affect the proper working of the telegraph circuit, or, as it is frequently termed, the **Morse circuit.** By the composite method, each conductor of the telephone circuit is used as an independent telegraph, or, as it is frequently termed, a Morse, wire, so that whatever transpositions are cut in, the relative positions of the conductors must remain unchanged at the terminals of the line. Reference to Fig. 20 will illustrate this point. Suppose that *l*, *k* are the two conductors of a telephone line running between the stations *a*, *b*, and that regular transpositions are cut in at the points *1*, *2*, *3*. If an extra, or special, transposition be cut in at *x*, for example, the relative positions of *l* and *k* will be reversed at the terminals; and as a result, the telegraph subscriber working on *l* at *b* will then be

connected to the one working on *k* at *a*. To overcome this difficulty with the standard system of transposing, the work of transposing must be done at such a time as the telegraph service is not given, so that the line may be tested out after the work is done and the proper reversals made at *a* or *b*, to insure the proper connections before this service is resumed. Again, the cutting in of a standard transposition necessitates the opening of the line for an appreciable time. Now, when telephone service only is given, the service may be continued over another circuit, by mutual arrangement between the two offices during this interval. With telegraph service, however, the case is different, because all telegraph wires are leased wires, and the subscribers require uninterrupted service during the day, and there are usually not enough

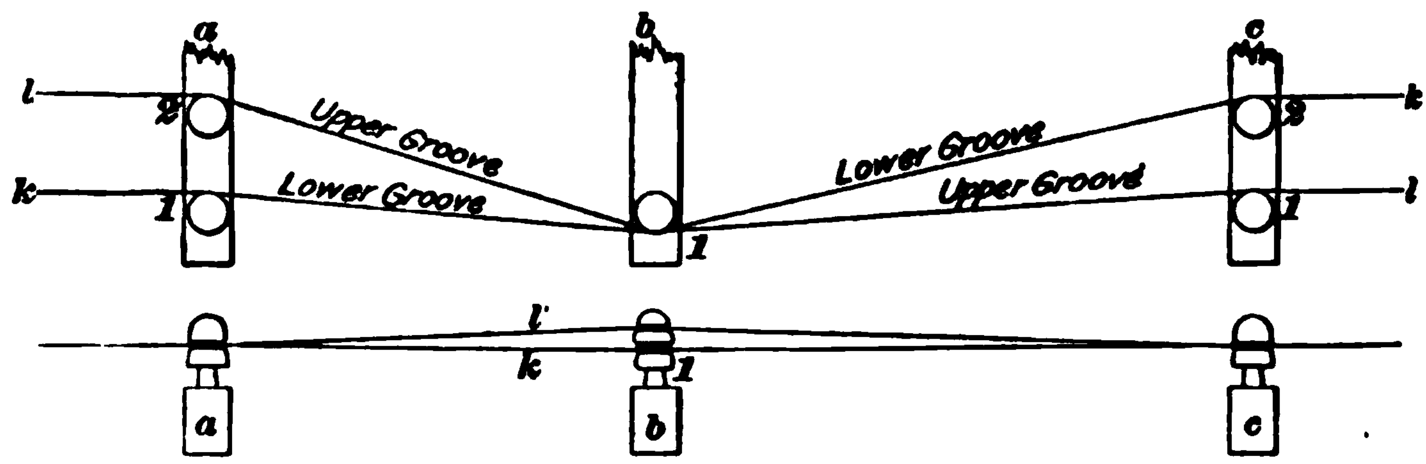


FIG. 21

spare wires to transfer the service. So that the cutting-in of special transpositions by the standard method is equally detrimental both with the simplex and composite methods.

30. Single-Pin Transpositions.—To overcome these difficulties, a new system of transpositions was invented by Mr. Murphy, chief of construction of the Westchester division of the New York Telephone Company. It is known as the **single-pin, or Murphy, transposition.** Old construction men, however, maintain that this system is not new, but that it was used in the early 80's in New England. However that may be, it possesses the distinct advantage of avoiding the opening of the line when it is cut in. The nature of this transposition is shown in Fig. 21. Suppose that the pole *b* is the one on which the transposition is to be made on the wires *l*, *k*, which take at the pole *a* the pins

2 and 1, respectively. A transposition insulator is placed on pin 1 at the pole *b* and the conductor *k* is tied in the lower groove at the pole *b*, while the conductor *l* is tied in the upper groove. On the next pole *c*, the conductor *k* will be tied in the usual manner to pin 2, while the conductor *l* will be tied to pin 1. Their mutual positions are thus reversed. To make this transposition, all that is necessary is to take up slack enough in the conductors to enable them to be shifted one pin to the right or left as the case may be. Thus, no cutting or opening of wires is required when making a transposition, and the relative connection of conductors remains unchanged.

Mr. F. F. Fowle says the single-pin transposition has the comparative advantage of less first cost and simpler construction. It can be cut in at any time, cut out, or moved several poles, at less cost and with much less work than in the case of a square, or ordinary, transposition. If transpositions occur frequently—say, every $\frac{1}{8}$ or $\frac{1}{4}$ mile—the line capacity is increased a few per cent. and the line inductance diminished, which is a slight disadvantage. The square transposition has the advantage of concentrating the entire transposition within a very short length and of not altering the separation of the wires. While the single-pin transposition changes the plane of the circuit, the wire separation is greatly reduced, which is an advantage. Since it requires two spans in which to make this transposition, it is possible, in case of excessive induction, to make on a given number of poles only one-half as many of the single-pin transpositions as of the ordinary square transpositions. The greatest disadvantage with this method seems to be the fact that the two conductors being superposed, the one above the other, for a short distance on both sides of the transposition insulator, they are liable to become crossed when coated heavily with ice. It has been introduced so recently that no actual figures as to its merit can be obtained, but it is now considered the standard transposition of the American Telephone and Telegraph Company, is being used on their long-distance lines, and is preferred for regular cross-talk transpositions.

BALANCED CIRCUITS

31. Telephone circuits are said to be **balanced** when the same amount of resistance, inductance, and capacity are similarly located or distributed in each side of the circuit. When there is not the same amount of any or all these quantities similarly distributed in each side of the circuit, it is said to be **unbalanced.** It is therefore theoretically impossible to have a perfectly balanced ground-return, or common-return, circuit; only complete metallic circuits can be perfectly balanced. An underground metallic circuit, if balanced and properly transposed, will be free from noise and cross-talk, but if properly transposed and not balanced it may be very noisy if there are disturbing circuits running parallel with it. One or more grounds may cause an otherwise quiet metallic circuit to be very noisy.

32. In Fig. 22, let *c d* be a disturbing wire; *m n*, a properly transposed and balanced metallic circuit of No. 12

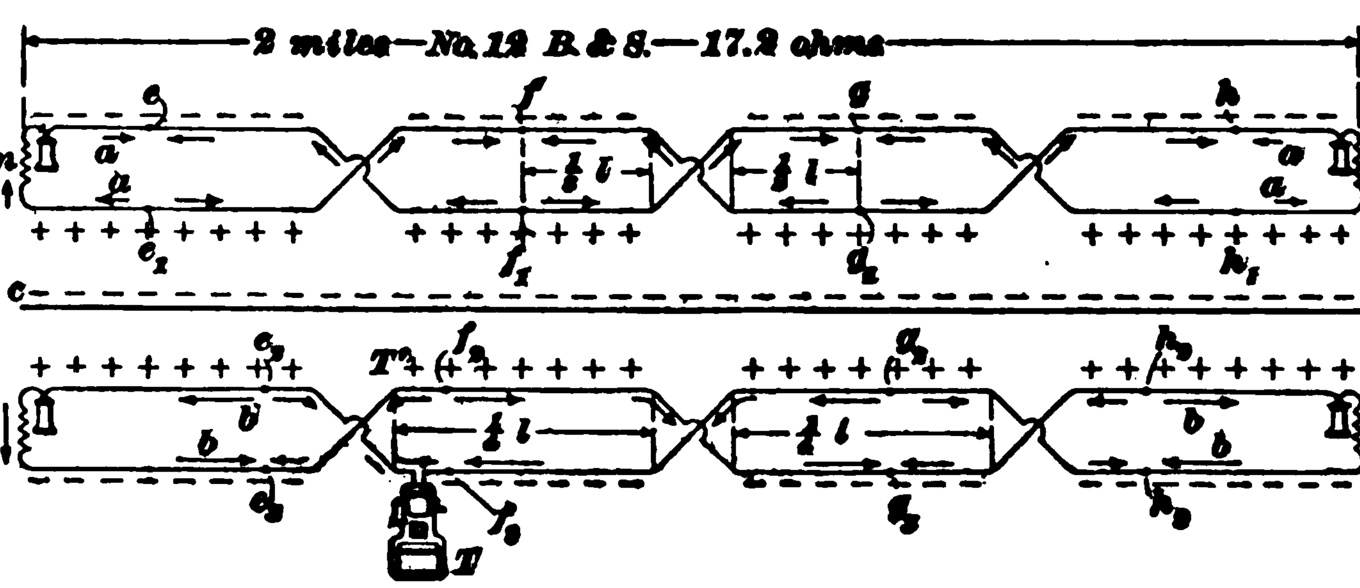


FIG. 22

B. & S. hard-drawn copper wire; and *o p*, a similar circuit, but unbalanced by the insertion of an ordinary series-telephone *T* in one side of the circuit. There are telephones in use at each end of each circuit, but *T* is not supposed to be in use at this time and hence its 80-ohm series-bell will be connected in series with one side of the circuit. In *m n*, the neutral points will occur at e, e_1, f, f_1, g, g_1, h, h_1, and the length of the arrows *a*, *a* may be taken to represent the equalizing currents

that flow through the end telephones each time the charge on the disturbing wire $c d$ passes through zero. This current is supposed to be small enough to produce no perceptible noise to ordinary subscribers at m, n.

Since the total resistance of each telephone line wire, which is 2 miles long, is about 17.2 ohms, it is evident that the insertion of an 80-ohm inductive resistance, such as an ordinary series-bell, will cause that particular part of the circuit to offer much more opposition to the flow of the induced charges than all the rest of the line circuit; consequently, T will become a neutral point, or very near one, as indicated. Hence, the neutral points will be now located about at e_1, e_1, f_1, f_1, g_1, g_1, h_1, h_1. In the circuit $m n$, the strength of the discharging current is equivalent to that produced on about one-eighth of the length of one wire, which may be considered as neutralizing an equal opposite charge on about the same length of wire on the opposite side of the circuit. In $o p$, however, the relative large impedance concentrated at T causes T to be very near if not exactly at a neutral point; and each arrow b, b, which may be taken to represent the strength of the discharging current, is equivalent to that induced on nearly one-fourth of the length of one wire, which may be considered as neutralizing an equal opposite charge on the same length of wire on the opposite side of the circuit. Hence, the current tending to produce a noise is about twice as great in the circuit $o p$ as in $m n$. This result may not be actually realized in practice, but it serves to explain the principle involved.

33. If a series-telephone T is looped in the circuit at a neutral point, it should not theoretically affect the quietness of the end telephones. If the transpositions are rearranged so that the present position of T becomes a neutral point, as may be done by locating the transpositions at the points e, e_1, f, f_1, g, g_1, h, h_1 in $m n$, the disturbing currents through the end telephones will be even less than indicated in $m n$; but this would mean an extra transposition in each section throughout the length of the line.

34. If a telephone is bridged across a line circuit, it will form a leakage path between the two sides of the circuit through which some of the charges can flow; hence, the charges and noises in the end telephones are reduced, especially when the intermediate telephone receiver is off the hook. Although a bridge across a metallic circuit tends to reduce disturbing currents through the end telephones, there is little to be gained by such practice because the voice currents can also leak through the bridged circuit and be reduced in magnitude at the receiving telephone about as much as the disturbing currents.

If a condenser is inserted in a line circuit, its location becomes a neutral point because the neutralizing charges cannot actually flow through the insulation sheets of a good condenser; however, the charges flowing in and out of the condenser may be increased by its presence.

35. Since exchange circuits are used to connect together two subscribers' lines, it is evident that the insertion of a resistance, inductance, or capacity in one side only of an exchange circuit tends to unbalance both lines. The evil effect due to a lack of balance will be less apparent with properly transposed line circuits. It is frequently advisable, where a resistance, inductance, or capacity—for instance, a relay or condenser—must be used in one side of an exchange circuit, to insert a similar resistance, inductance, or capacity in the other side, even if it cannot be used for any other purpose than to keep the circuit in a balanced condition.

TRANSPOSITION OF PHANTOM CIRCUITS

36. When one pair of wires is used as one telephone circuit, a second pair as a second telephone circuit, and the first pair with the two wires in parallel as one side, the second pair with the two wires in parallel as the other side, of a third telephone circuit, this third circuit is called a **phantom circuit**, because an extra circuit, apparently independent, has been secured without increasing the number of wires. Phantom circuits are treated elsewhere. The ordinary

transposition is of no effect, and unless specially transposed, phantom circuits will cross-talk and will be subject to induction from foreign circuits.

The transposition of a phantom circuit may be done in

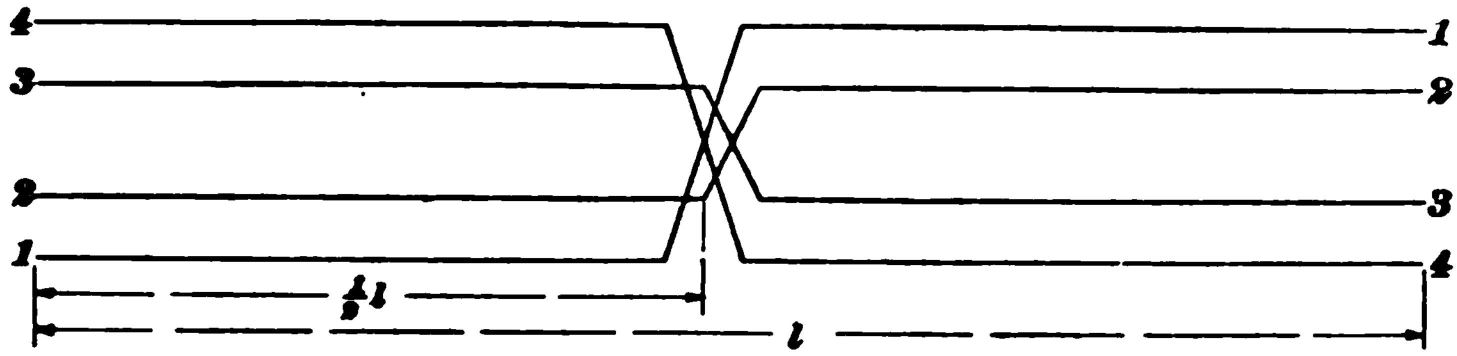


FIG. 23

several ways. Fig. 23 shows a transposition in which the phantom is transposed. Its two component circuits, while not transposed with respect to each other, are transposed

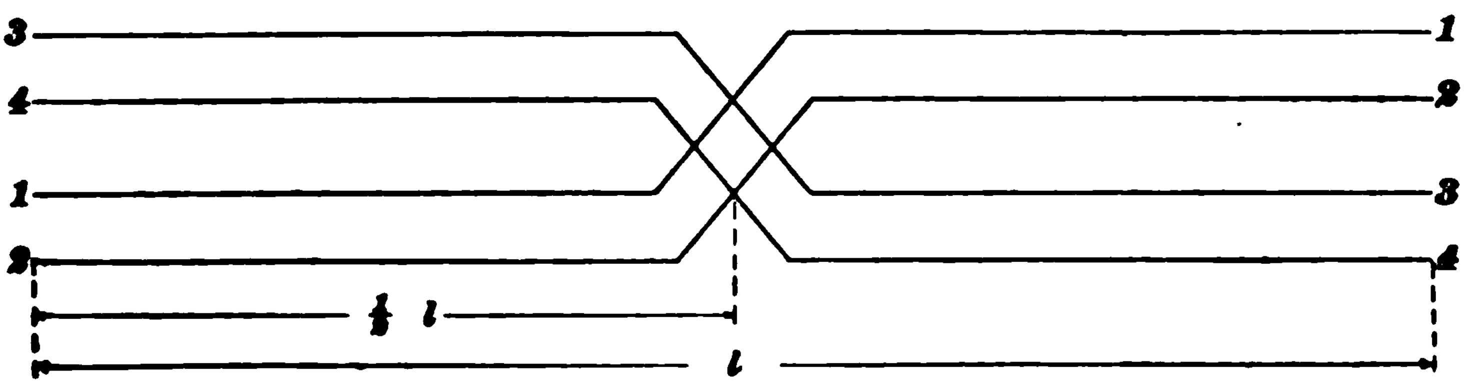


FIG. 24

with respect to any other parallel circuits and are also moved in position, thereby partly offsetting the latter transposition.

A second method is shown in Fig. 24, where the two component circuits are also transposed with respect to each other. Another method is shown in Fig. 25. If the regular transposition sections are not too long, the phantom transposition may be placed at a pole forming the junction between two

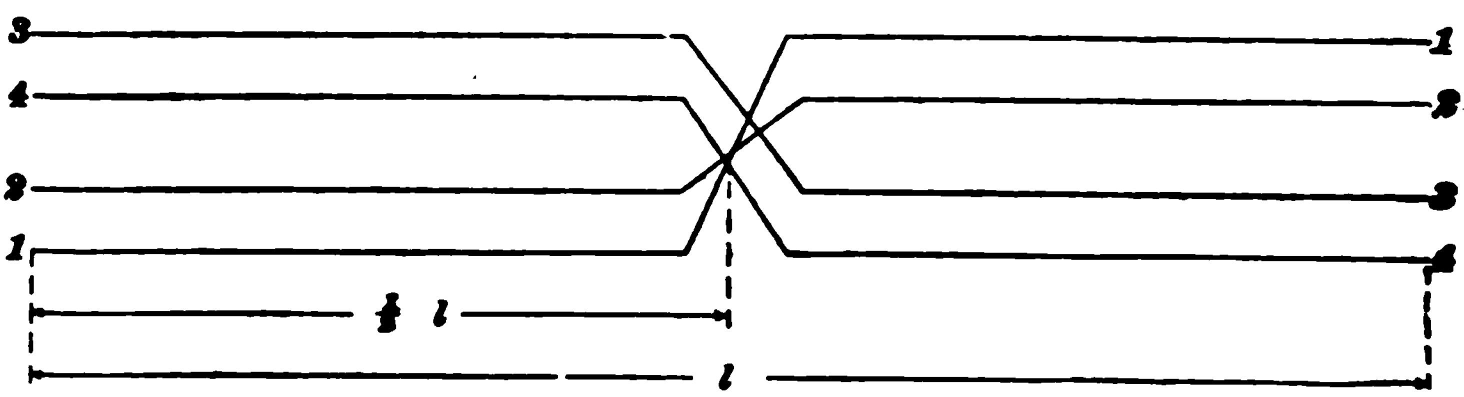


FIG. 25

sections, where it will have no effect on the regular sectional system; if it is placed within a section, it will upset the regular system of transpositions. If many phantoms are employed, it is best to lay out a section with only the phantom transpositions and then to superpose on it the additional simple transpositions to eliminate the cross-talk between the simple metallic circuits themselves. Phantom circuits have seldom proved to be sufficiently quiet, owing to the fact that the lines were not properly transposed so as to make the phantom circuit mutually non-inductive with other circuits. This is now accomplished, however, and phantom circuits are in constant use by the Bell and other companies for long-distance circuits.

ELIMINATION OF DISTURBANCES FROM FOREIGN CIRCUITS

DISTURBANCES FROM LIGHT AND POWER CIRCUITS

37. The transposition of telephone lines as a whole, to eliminate induction from foreign lines of high energy, carrying either high potentials or large currents, is an exceedingly important branch of the subject of transposition. This matter is becoming more and more important, especially with the development of high-tension transmission. If possible, run the telephone lines on poles on the opposite side of the street to the poles carrying high-potential light or power circuits. Where telephone lines run parallel with two-wire circuits carrying high-potential alternating currents, it is usually sufficient to transpose merely the telephone lines. The important feature is the manner of transposition when the exposure becomes complicated by the presence of transformers or arc lights in the alternating-current circuits.

Neutral points exist on the telephone lines opposite the points where transformers are joined to the alternating-current system, and hence transposition at these points will affect the disturbance in the telephone circuits but little, if any. Therefore, regular transpositions in the telephone

circuits should be located at these neutral points, if necessary, to eliminate cross-talk; whereas transposition should be located at intermediate points to eliminate disturbances due to the foreign circuits. A slight deviation of the regular transposition one way or the other from the exact points at which they should occur is immaterial. All telephone circuits should be transposed at a point midway between transformers and midway between arc lamps, in order to eliminate disturbances due to alternating-current and arc-light circuits, as well as at points where it is necessary to transpose the telephone circuits to eliminate cross-talk. Induction due to a single-wire, series, arc-light circuit represents one of the worst cases of trouble to be met with in practice.

38. An idea as to how to make transpositions to eliminate cross-talk and also disturbances from a neighboring

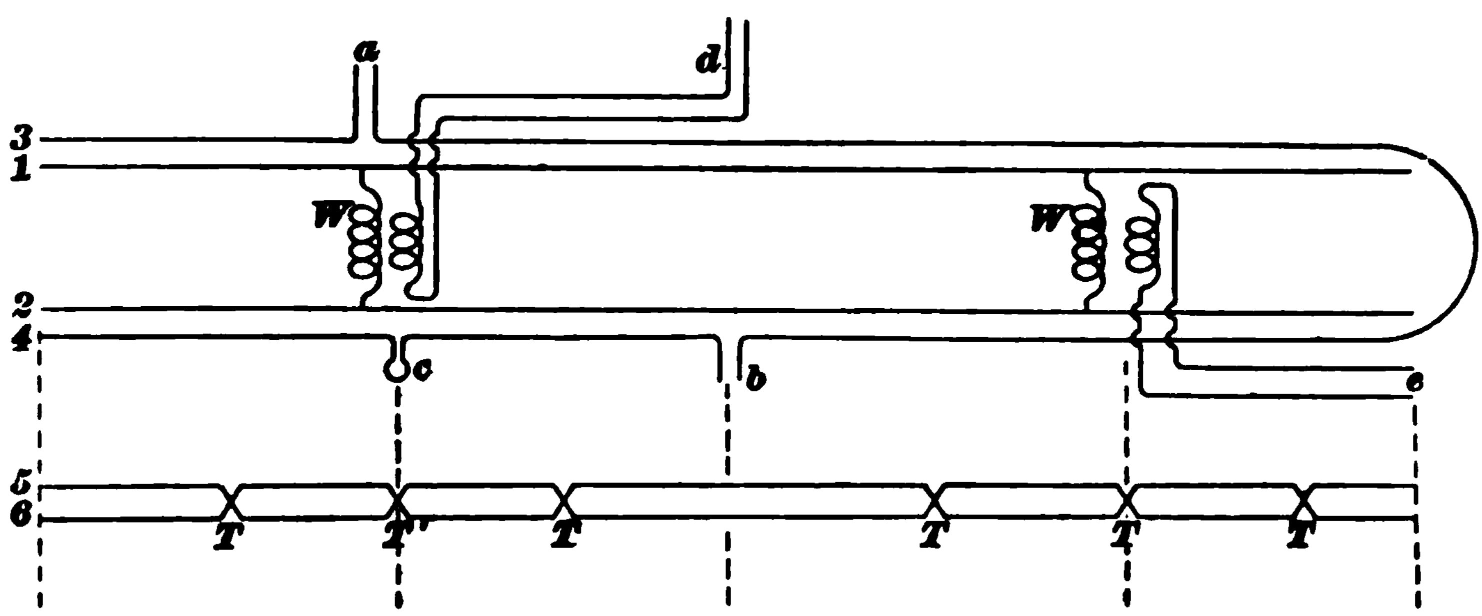


Fig. 26

arc-light and alternating-current circuit may be obtained by considering Fig. 26, in which *3–4* is a constant-current arc-light circuit with a lamp at *c* and loops *a*, *b* running to other lamps. *W*, *W* are transformers on a constant-potential alternating-current circuit with secondary circuits *d*, *e*. *T*, *T'* are the regular telephone transpositions, while *T*, *T*, *T*, *T* are transpositions properly located midway between changes in the other circuits to reduce the noise that the foreign circuits might induce in the telephone circuit.

The following general rule may be given to cover all cases. Treat as one section the distance between two

consecutive changes of any character in any of the disturbing circuits, and transpose all the telephone wires at the middle of each such section. These changes or discontinuities in the disturbing circuits occur where an arc light, for example, is inserted in one of the circuits, or where a transformer is bridged across the alternating-current circuit, or where any of the circuits change abruptly in direction or distance from the telephone circuits, or where additional alternating-current circuits begin to parallel the telephone lines, or where any of the disturbing circuits are transposed.

There is comparatively little trouble from metallic alternating-current circuits at a distance of 35 to 40 feet from the telephone line, such as would occur, for example, when the telephone line is on the opposite side of the street from an alternating-current line. The two systems usually may run along parallel with each other at such a distance apart for a mile before induction disturbances become serious. A single arc-light wire becomes troublesome if it runs parallel and close to the telephone line for only a few hundred feet.

DISTURBANCES FROM HIGH-POTENTIAL CIRCUITS

39. Transposition of High-Potential Circuits. Frequently high-potential systems are transposed for their own protection. When telephone circuits are run on such pole lines, the transpositions in the power circuits may be used to reduce induction in the telephone circuits; but in the case of separate telephone circuits, on a parallel pole line of separate ownership, it seems wiser to treat such transpositions as neutral points—to be opposite the junction of two transposition sections of the telephone line. In general; the induction from a three-phase line is slightly greater than from a single-phase line having the same wire spacing and current per wire. An explanation of the terms used here in connection with lighting, power, and high-potential transmission systems is beyond the scope of this Course. The separation between the wires should be as small as is consistent with the length of span. It seems to be fairly general practice to transpose high-potential systems twice within a section of length l, as

in Fig. 27, where two complete sections are shown. The length of a section l is usually 3 miles at least. On that account it is difficult to make use of the power-line transpositions to eliminate noise in the telephone line, and it is usually necessary to transpose the telephone line at points midway between the power-line transpositions.

40. Fig. 27 illustrates a single, metallic, telephone line exposed to a three-wire circuit, which may be considered as part of a three-wire Edison system, or a three-phase transmission line, or a three-wire two-phase line. Two transpositions of the three-wire circuit are necessary in this case in each section, each exposure being one-third of the total

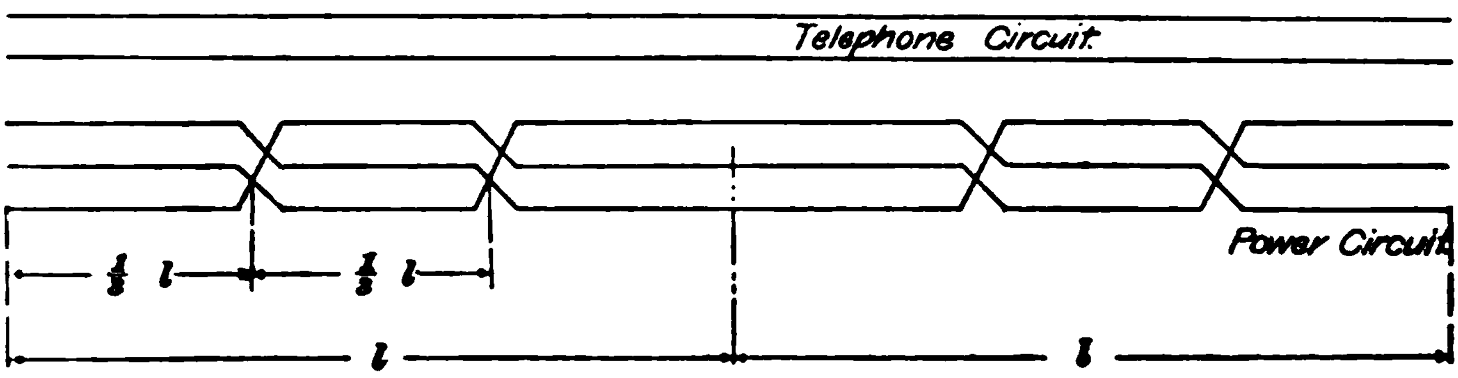


FIG. 27

length of exposure. Thus, the two-wire telephone line is exposed in each section l to three consecutive sections of the three-wire line in such a manner that the total current due to both electrostatic and electromagnetic induction vanishes.

In general, the transposition of a circuit having n wires will require $(n-1)$ transpositions, the distance from one end of the section of exposure to the first transposition being $\frac{1}{n}$th of the total length of a section of exposure, and each successive transposition occurring at a regular interval of $\frac{1}{n}$th of the total length of a section.

41. Where telephone lines have been run parallel with transmission lines along highways, separated by 15 or 20 feet, or by the width of the highway, the following practice has been employed: All the telephone circuits are transposed at every tenth pole, the cross-talk transpositions occurring

midway, so that transposition poles are five spans apart, the cross-talk and the induction transposition poles alternating. This practice, while it is somewhat uncertain of producing the best results, is probably best suited to certain requirements—where, for example, the method of sections would not produce any better results because of the physical unevenness and crookedness of the right of way.

42. Both Circuits on Same Pole Line.—On a long high-potential pole line it is usually very desirable to have also one telephone circuit. In Montana there is a power circuit in operation at 50,000 volts, and there is a possibility of going as high if not higher than 80,000 volts. For the long-distance transmission of power, it is quite customary to use high-potential systems requiring three wires, that is, three-phase systems. From a paper presented to the American Institute of Electrical Engineers by Mr. P. M. Lincoln, the following is abstracted.

43. Although a proper system of transposition will prevent the establishment of an electromagnetically induced electromotive force between the two telephone wires, it does not necessarily prevent the two wires from assuming an electrostatic potential that differs from that of the earth. In a properly transposed system, each telephone wire is the same average distance from each power wire. The potential, therefore, that the telephone system, as a whole, tends to assume from the electrostatic induction of the power wires is that of the neutral point of the power system. By neutral point is meant that point between which and each of the power wires the average electromotive force is the same. Under normal conditions, this neutral point is at ground potential. If, however, leakage takes place from one of the power conductors to ground, this neutral point will differ in potential from the ground, and the amount of this difference becomes greater as the resistance of the leak becomes less. In a three-phase system, when the resistance of this leak becomes zero, that is, when one live wire becomes dead-grounded, the maximum difference of potential between the neutral point

and ground occurs, and is 58 per cent. of the power-circuit voltage. In a 20,000-volt system, for instance, there may exist a potential of nearly 12,000 volts between the neutral point and ground. When the neutral point of the power line differs in potential from the ground, an electrostatic difference of potential tends to exist between the telephone wires and the earth, and will exist if the insulation of the telephone circuit is perfect.

The amount of this electrostatic potential between the telephone circuit and the earth will depend on the relative capacities between power and telephone lines on the one hand and between telephone line and earth on the other. The power and telephone lines may be considered as opposite plates of one condenser, and the telephone line and ground as opposite plates of another condenser. These two condensers being in series, they will distribute the total electromotive force in inverse ratio to their capacities. With the usual construction, the capacity between the telephone line and ground will not be less than that between the telephone and power wires, so that the potential of the telephone wires above ground will be equal to at least one-half the potential of the power-line neutral point above the ground. A grounded power line may thus cause a potential between the telephone wires and ground that will reach well into thousands of volts, and even a bad insulator may cause an electromotive force of hundreds of volts. In this connection, it is significant to note that in the great majority of cases the telephones become inoperative when a ground occurs on the power lines. This is to be expected because few telephone lines are built to stand up under a strain of even 1,000 volts, let alone 5,000 or 10,000 volts to ground. The first voltage strain comes not between telephone wires, but between the two telephone wires and ground. If a breakdown of its insulation, either partial or complete, occurs at some point and a partial ground results, the side of the telephone circuit on which a break may occur discharges to ground either partially or completely, and the other wire must discharge through the telephones to the same partial ground.

The points, therefore, that deserve careful consideration in the installation and operation of a telephone line, when it is to be operated in proximity to a high-tension transmission line, are the following: (1) high insulation, (2) proper transpositions, (3) use of bridging telephones instead of series-telephones, (4) making static capacity of telephone wires to ground as great as possible and capacity to power wires as small as possible.

44. **High Insulation.**—Insulation is put first as being the point of first importance. A ground on the transmission line is going to produce either a high potential or trouble on the telephone line. There is no reason why the telephone wires will not transmit speech properly, even if they do differ in potential from the ground. But to obtain this result, disturbing currents from the line wires to earth must be prevented by perfect insulation. When it is realized that the potential between the telephone line and ground may be as high as 30 per cent. of the potential between power wires, the importance of insulation will be better understood. By insulation, too, is meant the insulation throughout the entire line. There is little use in supporting the telephone wires on the poles with glass insulators capable of standing 15,000 or 20,000 volts, and then inside buildings attaching them directly to woodwork that may be damp, or to an instrument mounted on a damp brick wall. Above all, there is no use in putting up a line that may be able to stand a test of 15,000 or 20,000 volts, and then attach to this same line a lightning arrester that will break down at about 300 volts, as the standard telephone lightning arrester is expected to do.

When providing high-tension insulation for the telephone line, the insulation of the man using it should not be forgotten. This insulation of the telephone user is advisable, not only to protect him from the induced voltage, but also to protect him in case of a cross with the power line. The induced voltage is not so dangerous as its amount would indicate, because the current is limited to that which can pass through a condenser consisting of the power line as one

plate, and the telephone line as the other. It may be noted that the telephone insulation is subjected to high strains only when the power line is grounded or heavily unbalanced statically. This is just the time, however, that uninterrupted service of the telephone line is likely to be of the utmost importance.

45. Proper Transpositions.—The necessity of transposing the telephone line is almost so apparent as not to need comment; otherwise, continuous disturbances will exist, due both to electromagnetic and electrostatic effects. So far as the telephone line is concerned, transposition of the power wires is not so important. An untransposed power line cannot cause either electrostatic or electromagnetic disturbances between two properly transposed telephone wires, but only between these two wires and ground. If one side of the telephone line becomes grounded, it will be noisy. The amount that the statically balanced untransposed power line can elevate the telephone wires above the ground potential, is small compared to the effect of the power line when statically unbalanced, whether transposed or untransposed. If the telephone line is insulated to meet the worst conditions, it will be ample to meet the normal condition of an untransposed power line.

46. Use of Bridging Instead of Series-Telephones. The usual advantage of bridging over series-telephones has been considered elsewhere. It has also been shown that the insertion of a series-telephone in a properly transposed and balanced line will unbalance the circuit and probably make the telephones noisy, whereas bridging telephones rather tend to reduce the noise. Hence, bridging telephones should be used.

47. Capacity Between Circuits.—The capacity of telephone wires to earth should be made as great as possible, and that of telephone wires to power wires as small as possible. With the usual construction of long-distance transmission circuits, the potential of the telephone wires may be raised 20,000 to 25,000 volts above ground. The total

voltage between the neutral point of the power wires and ground may be considered as acting across two condensers, one consisting of the power and telephone wires, and the other the telephone wires and earth. To decrease the possible potential of the telephone wires to ground, therefore, one must either decrease the capacity between the power wire and the telephone wire, or else increase the capacity between the telephone wire and the earth, or both. This may be accomplished by increasing the distance between power and telephone wires, and decreasing the distance between telephone wires and earth. If the same supporting structure is used, there is a limit to which this can be carried, and even then the possible voltage between the telephone wires and earth may be prohibitive. The capacity of the telephone-wire earth condenser may be still further increased by bringing the earth to the telephone wires, instead of the telephone wires to earth. That is, one or more ground wires may be run in close proximity to the telephone wires, thereby increasing the capacity of the telephone-wire earth condenser to almost any desired limit. By this means, the possible potential between telephone wires and earth may be brought within limits where it may be taken care of with safety.

48. Disturbances from high-voltage alternating-current transmission, lighting, or power circuits are sometimes very difficult to eliminate. When the circuits are evenly balanced and free from grounds, crosses, etc., it is possible to have a neighboring telephone circuit free from disturbances.

On one 40,000-volt three-phase transmission line, 142 miles long, there were two circuits of six wires each. The three wires of each circuit were given one-third turn in opposite directions at every mile, and the telephone line, which was 5 feet below the power wires, was not transposed at all and yet was quiet when all circuits were in good order. Some claim that the proper spiraling or transposing of the power wires is more important than transposing the telephone wires. Telephone lines may even become disagreeably noisy when subjected to electrostatic induction from a neighboring

2,400-volt system, when one of the wires is accidentally grounded. When there is trouble in a telephone circuit due to a partial or dead ground on a high-potential power circuit, about the only remedy for the telephone man is to wait for the power company to remove the cause of the trouble.

DISTURBANCES IN GROUND AND COMMON RETURN SYSTEMS

49. Ground Return.—The cross-talk between grounded aerial lines of considerable length will ordinarily be serious, and there is no means of eliminating it by transposing. They may be operated for short lengths of a mile or so, without interference from cross-talk, if very low power (not very sensitive) receivers are used. For greater lengths, there will be serious cross-talk, and the low-power receiver is still necessary to remove extraneous inductive disturbances.

It is possible sometimes to lay out transposition points at which grounded repeating coils are inserted. This is interesting only as a theoretical proposition, because it reduces the efficiency and renders line maintenance very difficult.

50. Common Return.—If a common-return system is constructed free from ground connections, with the exception of a single ground connection that is sometimes placed on the common-return wire at the central office, trouble from earth currents and from leakage from electric-railway lines and other grounded circuits is eliminated if the work is properly done. With the common-return system, an exact inductive balance between the common-return wire and the various line wires cannot be obtained in practice, for it is obvious that the common-return wire cannot be so spaced with regard to all the other wires as to render an equal inductive influence on it and on all the other wires. However, this condition can be fairly well approximated by locating the common-return wire as near the center of the other wires as possible. For long-distance lines, however,

it is impossible to secure freedom from cross-talk by means of the common-return system, and therefore it should not be used.

51. Distance Between Telephone and Disturbing Circuits.—If two grounded circuits run parallel with each other, a series of experiments performed by Mr. Preece, of England, seem to show that making and breaking one circuit can be detected with a receiver connected in the other circuit, provided that the distance separating the two circuits is not greater than the length of the parallel portion of either circuit. If the circuit were so shortened that the distance between the two was greater than the length of either, no sound could be detected in the receiver. The results of these experiments are useful in running telephone leads into a building where it is necessary to run parallel, and close to, electric light or power circuits. Very often, noise in the telephone circuit is caused entirely by the proximity of the telephone wires in the building to an electric light or power circuit. However, if the length of the telephone wire that runs parallel or approximately parallel to the electric light or power circuit is kept shorter than the distance between the two circuits, trouble due to induction from the electric light or power circuit will seldom be produced. This cannot be relied on to always be the case, because the strength of the induced current will also depend on the intensity of the current in the electric light or power circuit and on the rate with which it varies.

THE HUMMING OF WIRES

52. The disturbance commonly known as **humming** is due entirely to the mechanical vibration of the wires. It can generally be eliminated without the use of *antihum devices*, by having the service, or drop, wire rather slack. If too much slack is undesirable, the use of a wire of heavier gauge, say No. 8 or 9, with moderate tension will generally prove effective. Humming may be prevented by breaking, in some manner, the uniform direct mechanical connection between the line wire and the building to which the drop line is attached and where the humming causes annoyance.

ANTIHUM DEVICES

53. All of the **antihum devices** are based on the plan of surrounding the troublesome wire with rubber or other insulating substances that will take up the vibrations. Humming may sometimes be prevented by splicing a piece of insulated wire to the line wire, and fastening the insulated wire around the insulator so that the vibrations from the line wire are not directly communicated to the insulated wire running to the building. Another plan is to splice a piece of heavily insulated No. 14 copper wire to the bare drop line, the joint being made just before the drop line reaches the insulator attached to the house. The insulated No. 14 copper wire is then secured to the insulator in any desirable manner, the loose end of the insulated wire being run through the wall and to the telephone, care being taken to leave it quite slack outside the wall.

A very simple antihumming device consists of about 6 feet of $\frac{3}{8}$-inch Manila rope cut in the drop wire near the house. A piece of insulated wire is used to connect the two ends of the drop wire across the rope.

Mr. A. V. Abbott says that humming may be prevented by wrapping the troublesome wire with a piece of soft rubber about 8 inches long, and then enclosing the same with a piece of sheet lead. A tie-wire should be treated in the

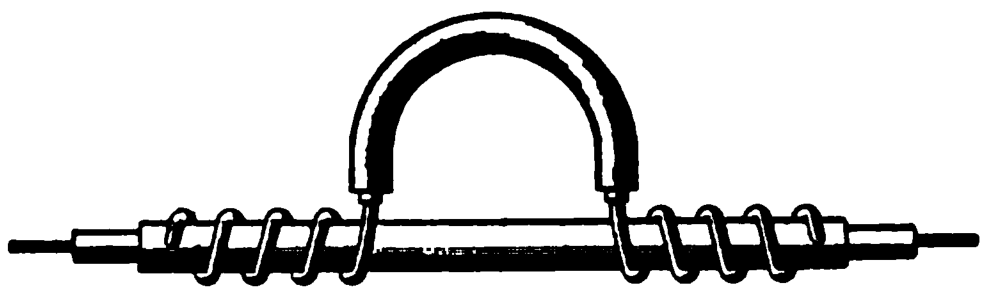


FIG. 28

same manner and used to tie the line wire securely to the insulator, as shown in Fig. 28.

54. English Antihum Device.—The arrangement shown in Fig. 29 is said, by a writer in The American Telephone Journal, to be quite extensively used in England to prevent the vibration of a telephone line wire from being communicated to the building to which it is attached. As

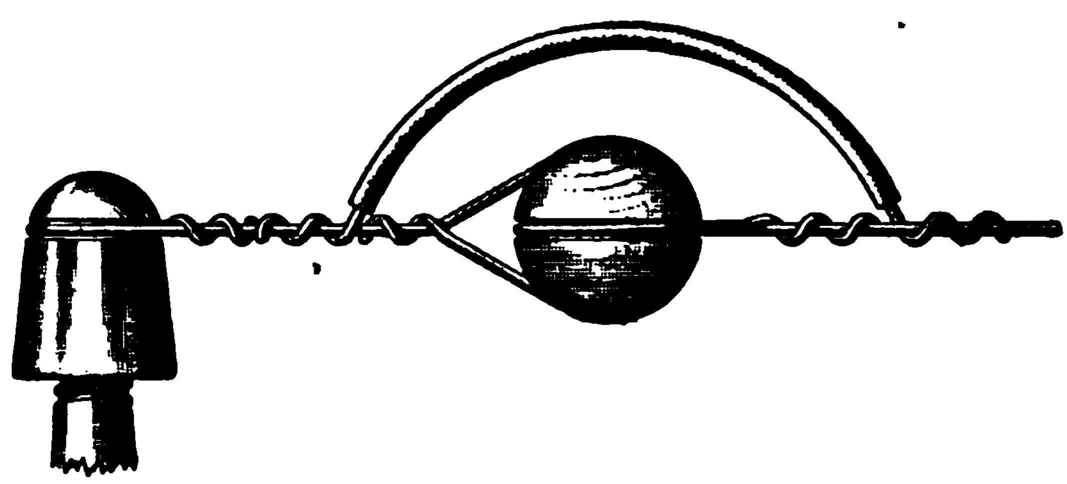


FIG. 29

shown in the figure, the line wire is cut about 18 inches from the insulator, where a hard wooden ball with a double groove is inserted, the continuity of the line wire being maintained by bridging over the wooden ball with a piece of insulated wire.

LONG-DISTANCE TELEPHONY

PUPIN'S SYSTEM OF LONG-DISTANCE TRANSMISSION

LIMITING DISTANCE OF TRANSMISSION OF TELEPHONE CURRENTS

1. To increase the limits of long-distance telephone transmission is a subject that has actively interested telephone engineers since about 1890. The limits of telephonic transmission depend on the nature of the circuit used. With open-wire lines, conversations can be successfully carried on over a distance of about 1,500 miles under favorable conditions. It has been stated, but also denied, that successful conversations cannot be held over an ordinary, bare, overhead, copper-wire line weighing 175 pounds per mile over more than 400 miles; nor through a 435-pound-per-mile, bare, overhead, copper-wire line over more than 1,000 miles. As this distance depends also on the power of the transmitters, sensitiveness of the receivers, distance between wires, and insulation resistance, such statements cannot always be relied on. The greatest distance over which articulate speech can be clearly heard through an ordinary submarine telephone cable is usually considered to be from 18 to 20 miles, and not over 78 miles through an ordinary, lead-covered, paper-insulated, telephone cable for underground or overhead use.

2. Four factors that reduce the distance over which speech can be transmitted are: the resistance of the line conductors, the insulation resistance of the line, its inductance,

and its capacity. The *conductor resistance* acts, according to Ohm's law, to reduce the amount of available current at the receiving end. The *insulation resistance* is a factor that determines the amount of leakage from the line and therefore affects the amount available at the receiving end. The factors, capacity and inductance, which under certain conditions tend to reduce the amount of available energy at the receiving station, act in a different manner from the two already mentioned.

Capacity tends to reduce the amount of useful current by setting up an electrical stress in the surrounding medium. Every conductor acts as a condenser, the wires forming the conducting plates and the surrounding medium the insulation. In the case of an open-wire line, the shortest distance between conductors is usually 1 foot, and the insulating medium is the surrounding air, the insulators, the pins, and the cross-arms. Owing to the fact that the conductors are separated from each other by a considerable distance, the capacity of a bare overhead line is very small. In the case of a cable, however, where the conductors are closely bunched together, and the insulating material is paper, cotton, wool, or rubber, the capacity is much higher, averaging about .08 microfarad per mile of length for a dry-core paper cable. In the case of a submarine cable, which is everywhere in close contact with that conductive element, water, there exists, in addition to the capacity between the conductors, a capacity between the conductors as a whole and the lead sheath or iron armor that is in contact with the water. The result is that the capacity of this type of cable is much higher than that of the cable used on land.

The *self-induction* of a circuit tends to reduce the amount of available current, by setting up a counter-electromotive force of self-induction, which tends not only to retard the current flow, but also to smooth down the peaks of the current waves. Moreover, this retarding effect is more marked for currents of high periodicity than for those of a lower periodicity. The result is that the former are retarded by inductance more than the latter. Since the currents of higher

periodicity correspond to the higher pitches of the human voice, the lower tones predominate at the receiving end, and articulate speech is rendered very imperfect or destroyed altogether.

3. Of the four factors already enumerated, the first two, conductor resistance and insulation resistance, form a class representing wasted energy. Using the mechanical analogue, they correspond to friction, or mechanical energy transformed into heat. The setting up of an electrostatic stress in a medium surrounding a conductor, or the setting up of a counter-electromotive force in this medium, means the storing up of energy, and hence the work so done cannot be said to be wasted. It therefore remains to devise some means of recovering, in the shape of a useful current, as much as possible of the energy so stored up.

Having in mind the fact that the counter-electromotive force of self-induction acts in a direction opposite to that of the electrostatic capacity, it was suggested that, if electromagnets of high inductance could be placed in the conductors of a cable at intervals throughout its length, they would, by increasing the inductance of the conductor, tend to offset the capacity of the cable. The use of electromagnets placed at intervals was suggested because it seemed impossible to make a cable whose conductors would have a sufficiently uniform inductance throughout their length, and it was supposed that these electromagnets would have the same effect on the conductors as if their inductance were uniform. Experiments on cables so designed were made in England by Sylvanus P. Thompson, Sir Oliver Heavyside, and others, but with far from encouraging results. So far from the electromagnets being beneficial, it was found that a circuit so loaded down would not produce as good results as it did without the coils. In some cases, transmission was utterly impossible with the coils in circuit.

4. The question then arose, under what conditions is a circuit loaded at intervals with coils possessing counter-electromotive force of self-induction equivalent to a circuit

possessing the same counter-electromotive force of self-induction uniformly distributed throughout its length. This was the problem solved by Prof. M. I. Pupin, and on its solution is based his system of long-distance transmission. In order to successfully comprehend the nature of this solution, it is necessary to study the transmission of electrical waves over circuits. The most important point to consider, first of all, is the nature of the reaction or reactions of the electrical circuit to the impressed disturbance. As a means of assistance, therefore, in the proper understanding of the subject, the nature of mechanical wave transmission will be taken up first and the resemblance then pointed out between that and the wave transmission of electrical energy.

MECHANICAL TRANSMISSION OF WAVES

5. Suppose that a tuning fork has its handle *n*, Fig. 1, rigidly fixed, one prong *a* attached to one end of an inextensible cord, the other end of the cord being fastened at *e*. Let the fork vibrate steadily, the vibration being maintained

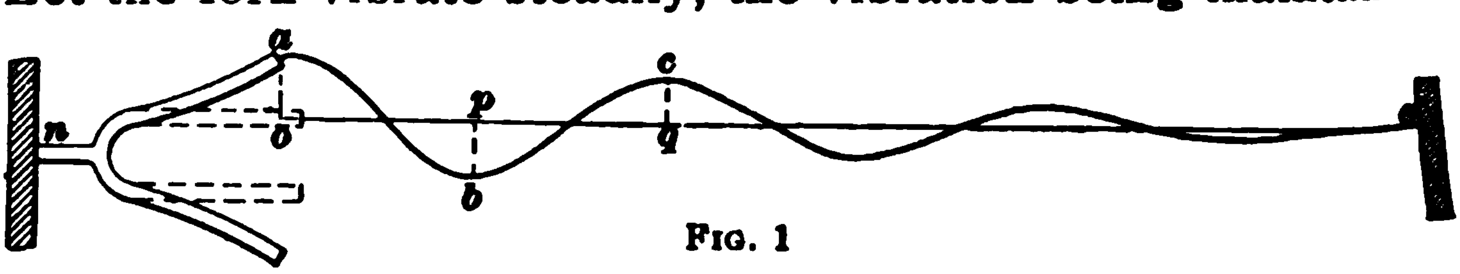


FIG. 1

in any convenient manner. If the frictional resistances are not negligibly small—if the string, for example, lies along a surface on which it rubs as it vibrates, or if it hangs slack instead of being under tension between the tuning fork and the point of attachment—there will be a dissipation of the propagated wave energy, and the motion of the cord will be as indicated in the figure. The amplitude of the waves will diminish from the point of the application of the disturbing force, until at the end *e* the motion has altogether died out. The point of application being at *a*, the amplitude of the first half wave at this point is shown by the line *o a*; that of the second half wave by the line *p b*; and that of the third half wave by the line *q c*; and the wave amplitude continues to diminish until the end *e* is reached; where there is little or no motion.

6. Considering the energy expended in causing the string to move, we observe: First, that there is friction to be overcome; the energy thus expended is transformed into heat and is lost, so far as wave production is concerned. It is measured by the percentage of the total energy so transformed. Second, there is the energy expended in producing the lateral motion of the string, sometimes called the energy expended in overcoming the inertia of the string. It is measured by the percentage of the total energy transformed into kinetic energy, that is, energy due to motion. Third, there is the elasticity of the string to be overcome; the energy thus expended is measured by the percentage of the total energy used in stretching the string. The amount of energy expended in moving the string may be shown by the equation

$$W = H + I + E$$

in which W = total energy supplied to the string;
H = energy lost as heat;
I = energy expended in producing lateral motion.
E = energy expended in stretching string.

Of these three quantities, H is lost, and I, since it has put matter in motion, is useful because it tends to give back to the string the energy originally expended in producing the lateral motion, hence it tends to keep the string vibrating. It increases with the mass of the string and with the velocity with which it is moved from side to side; hence, the greater the velocity of the disturbing force and the greater the mass of the string, the greater will be the energy expended in producing wave motion. The energy E expended in stretching the string is not lost, because the string will contract when the opposing external force is removed and it assists in keeping the string vibrating. By increasing the elasticity of the matter of which the string is composed, the elastic reaction is also increased, and likewise its power of transmitting wave motion.

If, therefore, the desire be to transmit a wave to the point c of the string with as little decrease in amplitude as possible, by agitating its opposite extremity, obviously the

heat reaction H must be made as small as possible, while the other two reactions I and E must be made as large as possible. This can be accomplished by decreasing to the utmost the friction, and increasing to the utmost the mass and elasticity, which can be secured by substituting for the cord a piece of clothes line, which is heavier and more elastic.

7. Should it be necessary, however, to continue the use of the same string, the experiment may be tried of increasing its mass by fastening a weight—say a ball of beeswax—at the

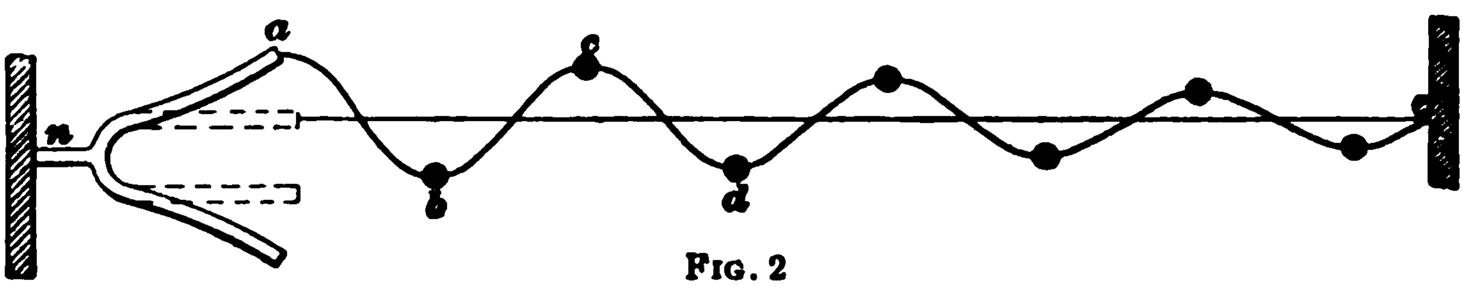


FIG. 2

middle point of the string, in order to increase the vibrating mass. This weight will become a source of reflections, and less wave energy will reach the point e than before. The efficiency of transmission will be smaller than before the weight was attached. Subdivide the beeswax so as to give about two equal pieces per wave length, and place them at equidistant points along the cord, as shown at b, c, d, etc. in Fig. 2. The efficiency of wave transmission will be much better than it was when all the wax was concentrated at a single point. By subdividing still further, the efficiency will

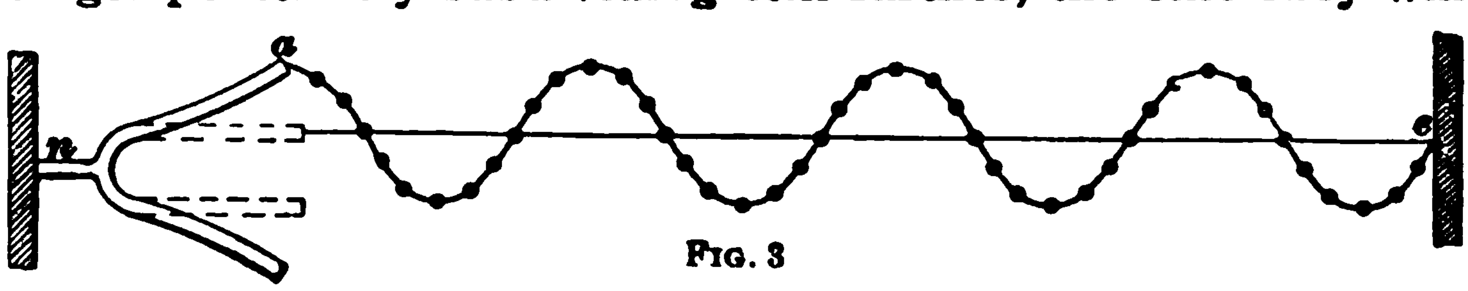


FIG. 3

be still more improved; but a point is soon reached where further subdivision produces an inappreciable improvement only. This point is reached when the cord thus loaded vibrates very nearly like a uniform cord of the same mass, tension, and frictional resistance. Fig. 3 represents the vibration of a cord carrying loads at about proper distances apart.

If the weights are placed too far apart, irregularly, or are too heavy or too light, then, instead of increasing the wave

transmission, they will act in the opposite way and render the cord less able to propagate energy in this manner than when it is unloaded altogether. It will be found that, when the proper total load is correctly subdivided and equal parts placed at suitable distances apart along the cord, the wave propagation becomes almost equal to that in a uniform cord of equivalent frictional resistance, mass, and elasticity. With the same string, there is no convenient way of increasing the elasticity, but the desired result can be sufficiently accomplished by the proper amount of loading.

8. Proper Distance Between Loads.—Experiments with cords of this kind show that the distance between the loads should be considerably smaller than one-half of the wave length of the wave that is to be transmitted, so that though a given cord may be properly loaded for some wave length, it may not be properly loaded for shorter wave lengths. It is impossible to load a cord in such a way as to make it equivalent to a uniform cord for all wave lengths; but if the distribution of the loads satisfies the requirements of a given wave length, it will also satisfy them for all longer wave lengths. It should be observed now that the wave length considered here is not the wave length of the cord without the loads, but the wave length that the frequency under consideration will have on the properly loaded cord, or, what amounts to the same thing, the wave length on a uniform cord of the same mass, tension, and frictional resistance as the loaded cord. This point is of fundamental importance, for the wave length corresponding to a given frequency may and generally will be much shorter on the loaded cord than on the cord without the loads.

TRANSMISSION OF ELECTRICAL WAVES

9. Comparing now the wave propagation of a string with the wave propagation in an electric circuit, it will be seen that the following analogies exist: A circuit on which is impressed a simple harmonic electromotive force has three reactions. The first is the reaction due to conductor and

insulation resistance, and is measured by the amount of energy used and wasted in producing heat; this is equivalent to the heat reaction in the case of the string. The second reaction is the inductance reaction, or the counter-electromotive force of self-induction, as it is more frequently called; this represents the amount of energy used in producing a magnetic field about the circuit, and is not wasted because the energy stored in this magnetic field can be made to give back to the circuit the current that produced it. This corresponds to the inertia reaction in the case of the string. The third reaction is the capacity reaction, which represents the amount of energy used in producing an electric stress between the conductor and the surrounding medium. Like the inductance reaction, this latter does not represent lost energy, since the potential of the electric stress so set up can be made to give back to the circuit the current that produced it. This corresponds to the elastic reaction of the string.

10. The amount of energy supplied the circuit may be expressed by the following formula:

$$W' = H' + I' + E'$$

in which W' = total energy supplied to the circuit;
H' = energy expended in producing heat reaction;
I = energy of inductance reaction;
E = energy of capacity reaction.

In order, as in the case of the string, to get a maximum amount of energy transformed into the two useful reactions, a minimum resistance must be secured by reducing the resistance of the line and improving the insulation as much as possible. In the case of an electric current, the reduction of the resistance requires an increase in the diameter of the conductor or the use of a material of higher conductivity. A point is very soon reached, however, beyond which the conductor cannot be increased in size on account of the extra cost, and it is not commercially practicable to use a material of higher conductivity than copper, so that the resistance reaction cannot be reduced beyond a fixed limit. Means must therefore be taken to increase the two useful

reactions in order to make the percentage of energy used up in their establishment as high as possible with respect to that represented by the other.

The inductance reaction varies directly with the self-induction of the circuit, so that by increasing this quantity its reaction is also increased. The capacity reaction on the contrary varies as the reciprocal of the capacity of the circuit, so that by reducing the capacity its reaction is increased.

11. It has been found that the inductance and the capacity of a line can be varied so little on an ordinary telephone circuit that no noticeable effects can be produced in their reactions, so that some other means must be found for increasing the reactance of one or both of these two factors. In other words, it is the same situation as that in which the mass and elasticity of the cord had to be increased without changing the cord. Since the inductance of the circuit could not be uniformly increased throughout its length, recourse was had to induction coils uniformly distributed throughout the circuit, just as weights had to be attached at regular intervals throughout the length of the string.

The first attempts at so loading a circuit, which have been mentioned in electrical journals, resembled the case where the weights on the cord were so placed that they interfered with, instead of assisting, the wave motion. The proper distance at which these coils should be placed, together with their inductance, was calculated by Professor Pupin after the solution of a very complex mathematical formula.*

12. The following discussion, which is an abstract from a small portion of Professor Pupin's paper read before the American Institute of Electrical Engineers, May 19, 1900, is given to show under what conditions a non-uniform conductor,

*The mathematical discussion of the theory of loaded telephone lines is fully given by Prof. M. I. Pupin in the Transactions of the American Institute of Electrical Engineers for March, 1899, and May, 1900, and in the Transactions of the American Mathematical Society for July, 1900, and by Dr. G. A. Campbell in the Philosophical Magazine for March, 1903. These papers were reprinted in most electrical periodicals of about the same date.

that is, a properly loaded conductor, is equivalent to a corresponding uniform conductor. Let s be the distance between two load coils, l the length of one wave, and $m°$ the angular distance between two inductance coils. For instance, if there are 5 coils per wave length, the length of one complete wave being 10 miles or 360°, then the distance between two coils is 2 miles or 72°. Since a wave length is equivalent to 360°, and the circumference of 360° is 2π for unit radius, then the arc, or angular distance 2π, corresponds to one wave length. Then

$$\frac{m°}{2\pi} = \frac{s}{l}$$

That is, the angular distance between two coils divided by the angular length of one wave is equal to the linear distance between two coils divided by the linear length of one wave.

13. The law that determines the degree of equivalence between a non-uniform conductor and its corresponding uniform conductor is then stated to be as follows: A non-uniform conductor is as nearly equivalent to its corresponding uniform conductor as $\sin \frac{m°}{2}$ is to $\frac{m°}{2}$; that is, as the sine of one-half the angle $m°$ is to the length of the arc subtending one-half the angle $m°$.

It will be well to state here more fully the meaning of the expression "equivalence between a non-uniform conductor and its corresponding uniform conductor." All that we know about a wave of a given frequency is that it has a certain wave length and a certain amount of attenuation. Hence, if a wave of a given frequency has the same wave length and the same attenuation on a non-uniform conductor as it has on the corresponding uniform conductor, the two conductors are equivalent to each other. If these two quantities differ by, say, 3 per cent., an approximate equivalence up to within 3 per cent. exists.

14. Attenuation means the decrease in intensity, strength, or amplitude of an electrical wave between the transmitting and receiving ends. Contrary to the conception

of an electric current frequently held, the maximum or mean value of an alternating or variable current is not the same in all parts of a line wire, even at any given instant, but decreases gradually as the distance from the transmitting end increases. This is not necessarily true for a steady direct current, however. This reduction is due to the resistance of the conductors, insulation resistance, and improper relative values of distributed capacity and inductance of the line circuit.

Distortion of an electrical wave is due to the fact that some electrical property (usually, distributed capacity) of the line acts unequally on the component waves of different frequencies that together make up a complex current wave representing articulate speech, the result being that the change in the phase relations and intensity of the various overtones and the fundamental tone produces a change in the shape of the current waves that renders the articulation more or less defective. Increased distance interferes with the transmission over a uniform conductor, not only on account of the diminished volume of the sound transmitted, but also on account of the rapid loss of articulation. This manifests itself at first as an apparent lowering of the pitch of the voice.

15. From the formula $\frac{m^\circ}{2\pi} = \frac{s}{l}$, it will be seen that m° is inversely proportional to the wave length l, so that for a given distance between the coils the degree of equivalence diminishes as the wave length diminishes. In other words, the shorter the wave length l the less must be the distance s between the coils to give the same value for $\frac{s}{l}$ and hence for $\frac{m^\circ}{2\pi}$. If a wave of complex harmonic frequency, such as occurs in telephony, be transmitted over a non-uniform conductor, the action of the conductor will be different for the different components of this complex harmonic wave. If, however, the non-uniform conductor acts with sufficient approximation as a uniform conductor toward the highest important frequency of this complex wave, its

approximation to a uniform conductor will be even higher for the lower frequencies, and thus for all the frequencies of the wave.

The following numerical example will illustrate this point more clearly: A twin conductor, such as is employed for telephone cables, has a length of 250 miles. Let its constants have the following values per mile: inductance = 0, resistance = 9 ohms, mutual capacity = .074 microfarad. According to the high but definite standard that the New York Telephone Company employs, the limiting distance of telephony over such a cable is 39 miles. According to the lower standard that is maintained in long-distance telephone work, the limit is 78 miles. Professor Pupin says his experiments seem to verify these figures and that at a distance of 100 miles telephony over such a cable is very poor, in fact, impracticable, and at a distance of 125 miles impossible. It is proposed now to decrease attenuation and distortion over such a cable by the insertion of inductance coils at periodically recurring points.

16. Attenuation Constant.—The percentage p of the current leaving the transmitting end that will reach the receiving end is given by the formula:

$$p = \frac{1}{2.718^{dB}} \qquad (1)$$

in which d = length, in miles, of a pair of conductors;
B = number called the attenuation constant.

By taking for granted that one solution to be given presently is correctly made, this formula, which requires the use of logarithms to get a numerical value for p, need not be used by the reader.

The general formula for the attenuation constant is as follows:

$$B = \sqrt{\pi n C\left(\sqrt{4\pi^2 n^2 L^2 + R^2} - 2\pi n L\right)} \qquad (2)$$

in which n = frequency;
R = resistance per unit length of circuit, in C. G. S. units;
L = inductance per unit length of circuit, in C. G. S. units;
C = capacity per unit length of circuit, in C. G. S. units.

Professor Pupin states that, if $2\pi n L$ is large in comparison to R, which is usually the case during a conversation for ordinary line circuits used in telephony, the formula for a single conductor becomes

$$B = \frac{R}{2}\sqrt{\frac{C}{L}} \qquad (3)$$

which is independent of the frequency. Hence, all frequencies are attenuated alike, and high inductance not only diminishes attenuation, but also reduces distortion.

Furthermore, if C is the mutual capacity alone, as in the case of a pair of conductors, $2R$ and $2L$ must be used in place of R and L when a pair of conductors is under consideration. Making this substitution, and expressing R, L, and C in ohms, henrys, and microfarads per mile, we get (according to Professor Pupin)

$$B = \frac{R}{1{,}000}\sqrt{\frac{C}{2L}} \qquad (4)$$

Say that it is required to have $B = .0146$ in the circuit under consideration. Assume that the introduction of the inductance coils adds 9 ohms per mile, so that $R = 18$ ohms. Substituting these values of R, C, and B in the last formula and solving for L, we find that

$$.0146 = \frac{18}{1{,}000}\sqrt{\frac{.074}{2L}}, \text{ hence}$$

$$L = \frac{.074 \times 18^2}{2 \times .0146^2 \times 1{,}000{,}000} = .056 \text{ henry}$$

It may be well to state here that, if the two coils for a pair of telephone wires are wound on the same spool or iron core, one coil being connected in series with each wire, and the self-inductance of each coil is a henrys and the mutual inductance between the two coils is b henrys, the total inductance of each coil to be used for L in the last formula is the sum of the mutual and self-inductance, that is, $a + b$ henrys.

The percentage of the current leaving the transmitting end that will reach the receiving end will be, according to the formula, $p = \frac{1}{2.718^{dB}} = \frac{1}{2.718^{250 \times .0146}} = .0259$, or about $2\frac{1}{2}$ per

cent. This is quite sufficient for telephonic purposes; but it should be observed that better efficiency of transmission could be obtained by making L larger.

17. The same cable, having an inductance of about .0012 henry and a resistance of 9 ohms per mile, would only allow, at a frequency of 600, about .0004 per cent. of the initial current to reach the distant end; that is, the current at the receiving end would be 6,000 times larger with the coils than without them. This can be verified by first determining with these quantities the value of B and then the value of p by the formulas already given.

18. Determination of Wave Length.—The next step is to find the wave length for the highest important frequency in telephony over a uniform wave conductor having $L = .056$ henry, $R = 18$ ohms, $C = .074$ microfarad. The best telephone practice assumes that 750 periods per second is the highest frequency of any importance. The length l, in miles, of an electric-current wave over a uniform conductor of this description is obtained from the formula

$$l = \frac{1{,}000}{n\sqrt{2\,L\,C}}$$

in which n = frequency, in periods per second;
L = inductance, in henrys per mile;
C = capacity, in microfarads per mile.

EXAMPLE.—What is the length, in miles, of a current wave through a uniform conductor whose inductance per mile is .056 henry and capacity per mile is .074 microfarad for a frequency of 750 periods per second?

SOLUTION.—Substituting in the formula, we find l

$$= \frac{1{,}000}{750\sqrt{2 \times .056 \times .074}} = \frac{1{,}000}{750 \times \sqrt{.008288}} = \frac{1{,}000}{750 \times .091} = 14.65 \text{ mi.} \quad \text{Ans.}$$

The velocity of propagation of electrical waves of telephonic frequency over wires may be anything from the velocity of light down to a few inches, or even less, depending on the inductance, resistance, and capacity of the line. The less the velocity, the shorter will be the wave length for a given frequency.

19. It has been shown that the inductance per mile should be at least .056 henry, and that the wave length through an equivalent uniform conductor for a frequency of 750 is 14.65 miles. Hence, one coil of .056 henry per mile will give about 14.6 such coils per wave length, which is sufficient. Suppose then that at each mile we place a coil of inductance L = .056 henry and a resistance R = 9 ohms. It has been stated that $\frac{m^\circ}{2\pi} = \frac{s}{l}$, then $m^\circ = \frac{2\pi s}{l}$. In this case s = 1 mile, hence $m^\circ = \frac{2\pi}{14.6}$. Therefore, the angular distance, or the number of degrees of a wave per mile for a frequency of 750 periods per second of the non-uniform conductor thus obtained, will be $\frac{2\pi}{14.6}$. The degree of equivalence of this non-uniform conductor to its corresponding uniform conductor is measured by the degree of equivalence of $\sin\frac{m^\circ}{2}$ to $\frac{m^\circ}{2}$, or as $\sin\frac{\pi}{14.6}$ to $\frac{\pi}{14.6}$, or as $\sin\frac{180^\circ}{14.6}$ to $\frac{3.1416}{14.6}$, or as $\sin 12^\circ\ 18'$ to .2151. The $\sin 12^\circ\ 18'$ = .2130 (see a table of natural sines). Now .2130 differs from .2151 by less than 1 per cent. of .2151; hence, $\sin\frac{m^\circ}{2}$ differs from $\frac{m}{2}$ by less than 1 per cent. of the value of $\frac{m}{2}$; therefore, for a frequency of 750, the wave length and the attenuation constant on the non-uniform conductor will differ from the wave length and attenuation constant on the corresponding uniform conductor by less than 1 per cent. of the values of these constants. Such a difference cannot be detected by any of the experimental methods that are at present available for investigating wave propagation. In telephonic transmission, the ear could not detect it. For lower frequencies, the differences will be even considerably smaller. Hence, the non-uniform conductor thus obtained will represent a uniform, non-attenuating, distortionless conductor for telephonic transmission. The methods of deriving, proving, or further explanations

concerning any of these formulas are too complex to be given here; if desired, Pupin's original papers should be consulted.

20. It should be observed that, in the case of a submarine cable of, say, 2,000 miles, the attenuation constant should be much smaller than the value of B given above, in order to get sufficiently satisfactory results. Now, the capacity per mile of a submarine cable is about four times as large as the capacity of the telephone cable just described. Hence, both on account of the long distance and also on account of the greatly increased capacity, the inductance per mile will have to be much larger than in the case just discussed. But high inductance and large capacity will give a very short wave length. For instance, if in the case of the submarine cable having six times the capacity we employ an inductance

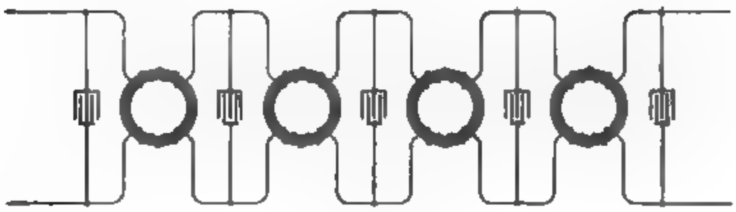


FIG. 4

six times as large as in the case of the telephone cable, we will obtain for the frequency of 750 periods per second a wave length of only $14.6 \div 6 = 2.43$ miles, since

$$\frac{1,000}{n\sqrt{6\,L \times 6\,C \times 2}} = \frac{1}{6}\left(\frac{1,000}{n\sqrt{2\,L\,C}}\right)$$

Hence, since the inductance coils will have to be placed apart at one-sixth of the distance employed in the case of the telephone cable, the distance between them will be about 880 feet. The distance between the inductance coils depends entirely on the circumstances of each particular case.

21. Fig. 4 illustrates the Pupin method of inserting inductance coils; the condensers shown merely serve to represent the distributed capacity that it is the function of the coils to overcome. Each coil has two windings, one for each line

wire, on the same ring-shaped, or toroidal, core composed of very fine, insulated, hard-steel wire. The core is made of fine, insulated wire to reduce eddy-current losses, and of quite hard steel to reduce the hysteresis loss. The twin inductance coils used by Professor Pupin in some of his trials consisted each of two coils wound on one spool 125 millimeters diameter by 125 millimeters high and separated by a sheet of cardboard $\frac{1}{32}$ inch thick. The coil when finished was boiled in beeswax at a temperature of about 280° F., in order to drive out all moisture and insure good insulation. Each coil had 580 turns of No. 20 B. & S copper wire. The average self-inductance of one of these coils is .03 henry, and the mutual inductance is .028 henry. Each coil, therefore, when connected in the line, has an effective inductance of .058 henry.

EXPERIMENTAL TRIALS

22. Experiments Through Underground Cables. A cable between Berlin and Potsdam, 20.2 miles, consisting of twenty-eight pairs of copper conductors, each conductor 1 millimeter in diameter (nearly equivalent to a No. 18 B. & S.) was equipped with Pupin load coils. The distance between the coils, which could be placed only at junction boxes, was about 4,264 feet. Each coil had a resistance of 4.1 ohms and an inductance of .062 henry, and the resistance of the cable conductors including the coils was 37.8 ohms per mile. The distributed capacity was .595 microfarad per mile. By the introduction of the coils, the self-induction of the circuit, which was .00048 henry per mile at 900 cycles per second, was increased 200 times. A similar circuit 101 miles long gave as good transmission when loaded as an unloaded circuit of similar conductors only 20.2 miles long.

When 3.38 milliamperes, at a frequency of 900 cycles per second, flowed into the transmitting end of the Berlin-Potsdam cable equipped with load coils, 1.2 milliamperes reached the receiving end; whereas only .17 milliampere reached the receiving end when the cable was unloaded.

The transmission over a cable 60.6 miles long was forty-eight times better than over a similar unloaded cable of the same length. Experiments by the same parties showed that for a frequency of 600 or more (giving a wave length of 13.05 miles or less) there should be at least five coils per wave length, each coil having an inductance of .11 henry, on a line having an inductance of .121 henry, and a capacity of .064 microfarad per mile.

These experiments were claimed to show that the Pupin system would enable the weight of copper for equal transmission to be reduced to one-fourth; or with the same weight of copper per mile it would be practical to telephone over a distance four times as great. In the foregoing experiments, the result of connecting a long loaded line to a relatively short unloaded subscriber's line was not considered.

23. Bare Overhead Lines.—Several long-distance lines of the American Bell Telephone Company between Chicago and New York have been fitted with the Pupin load coils, and it is stated that the loudness of transmission has been increased about 100 per cent. These lines consist of No. 8 Birmingham gauge hard-drawn copper wire (nearly equivalent to a No. 6 B. & S. gauge), and the load coils have been connected in circuit every 2½ miles. As the distance is about 900 miles, this means the installation of 360 coils on each line. On two of the Chicago-New York circuits, the coils are installed in wooden cases and on the other line in iron cases. The cases are mounted on the poles near the cross-arms, much as a transformer would be suspended on an electric-lighting pole. At each pole, the wire is dead-ended on transposition insulators, and the apparatus, which is embedded in the case in pitch, is connected in series with the line, all joints being soldered. The use of the two styles of cases was to ascertain the one best suited for the service, and while the wooden box has better insulating qualities, it is thought the iron case will come into more common use on account of its reliability and freedom from injury from the elements or from reckless marksmen.

A long-distance circuit between Chicago and Philadelphia was also equipped with the load coils. This line is of No. 12 N. B. S. (New British Standard) gauge copper wire, which is nearly equivalent to a No. 10 B. & S. gauge. A line between New York and Philadelphia is being equipped, and it is stated that part, if not all, of this circuit will be run underground.

24. Transmission Over Submarine Cable.—One of the longest submarine cables used for telephone transmission extends from St. Margarets Bay to La Panne through the English Channel. It is 54.6 miles long and contains one pair of telephone conductors and one pair of telegraph conductors, but there is no interference between the two circuits. The resistance, capacity, and inductance per kilometer per single conductor are 3.83 ohms, .144 microfarad, and .00055 henry, respectively. For a circuit of one pair, the inductance and resistance are double and the capacity one-half these values. The insulation resistance is not less than 500 megohms per mile. The attenuation constant B for 800 periods per second is very close to .0268. This is an example of a good cable in which, however, no means was taken to increase the inductance by the use of iron wire or coils.

A cable 46.5 miles long was laid from Cuxhaven to Helgoland to work with a bare overhead line of bronze wire, 4 millimeters in diameter and 373 miles long. The resistance, capacity, and inductance per kilometer per single conductor are 1.36 ohms, .0914 microfarad, and .00214 henry. Each telephone conductor had wound spirally about it an iron wire .3 millimeter in diameter, the inductance thus being increased from about .00082 to .00214 henry per kilometer. The attenuation constant B for a frequency of 800 periods per second is very close to .006, which is considerably less than that for the preceding cable. This is an ideal method of increasing the distributed inductance of a cable conductor, but the increase in inductance cannot be made to increase as fast as the diameter of the conductor must be increased for

increased distances. Hence, a limit is soon reached, in practice, beyond which a further relative increase in inductance can only be obtained by some such method as proposed by Professor Pupin. The winding of an iron wire around a conductor to increase its inductance is advantageous only when the cross-section of the conductor is large and the resistance low. The transmission of speech is very good over the cable alone and also over both the cable and the bare overhead line.

Considerable information about five submarine cables is given in the accompanying table, while in Fig. 5 is shown the relative values of the attenuation constants and also the variation of the attenuation constants with the frequency. Curve *1*, for instance, represents the variation of the attenuation constant for cable No. 1 from about 200 to 1,400 cycles per second. Curve *6* is given for an ordinary cable containing a wire 1 millimeter in diameter and curve *0* for a bare overhead bronze wire 3 millimeters in diameter. Bronze wires

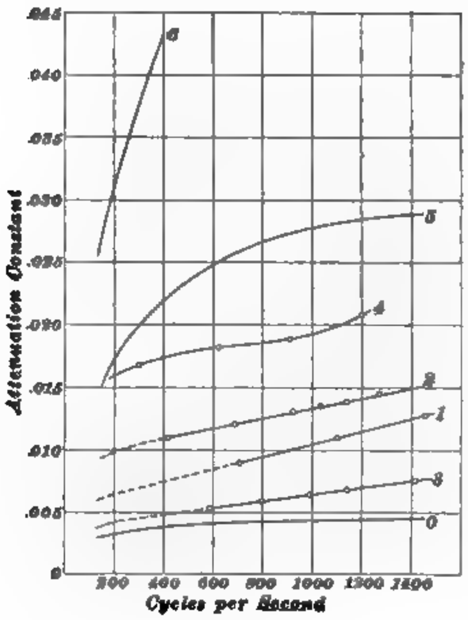


FIG. 5

are used considerably in Europe. The results given in the table, which is condensed from an article in Telephony for December, 1904, are for the telephone conductors only at a temperature of 15° C. The mean permeability of the iron wire wrapped around the telephone conductors is said to be 101. The values for capacity and self-inductance apply to each conductor in a pair. For one

pair as a circuit, the self-inductance and resistance are said to be double and the capacity one-half the values given. By reason of hysteresis and eddy-current losses, the self-inductance decreases somewhat with increasing frequencies. The impedance factors are factors by which the simple resistance must be multiplied to give the impedance. The capacity per kilometer of No. 1 measured with continuous current was .1624 microfarad; of No. 4, .1745 microfarad; with alternating current, .1435 microfarad and .1632 microfarad, respectively. The inductivity of dry-paper insulation and impregnated insulation was 1.6 and 3.54, respectively.

25. Professor Pupin's Claims.—By his method, Professor Pupin claims that it is possible to telephone and telegraph over much greater distances; that if the distance remains constant, this method enables wires of smaller size to be used, thus decreasing the cost of installation; and that with the same size of wire as in use at present, the distance of transmission may be greatly increased.

Professor Pupin is confident that, by the use of his coils, it will be possible to carry on a conversation without difficulty between New York and San Francisco. It is claimed that connected circuits of an aggregate length equivalent to such a line have already been successfully talked over. Pupin load coils are proving more successful on underground cable circuits in large cities than on bare overhead lines, probably because there is more opportunity for improvement in transmission and also because the insulation resistance is higher and more constant. In regard to the use of his retardation coils on ocean cables, Professor Pupin is quoted as saying that no effort will be made to establish an ocean telephone system until the land work has been thoroughly tried.

OTHER SOURCES OF TROUBLE

26. Line Leakage.—Considering only the resistance, inductance, and capacity of a line, it would not now be very difficult to transmit voice currents over very long distances

by Pupin's method without loss in clearness and in loudness. There are, however, other sources of trouble. For instance, on very long lines, there is quite an appreciable loss due to the fact that the insulation of the line is not perfect and the leakage increases with the length of the line. Even this could be overcome if the insulation resistance remained constant, but on bare overhead lines it varies so much with the state of the weather that it is a very serious trouble.

27. Terminal Taper.—A much more serious source of loss in some lines is that wherever the inductance loading of a line changes abruptly—as it does in repeating coils, terminal apparatus, junction of bare lines with cables, etc.—a reflection of the electric wave takes place. Where long-distance lines have to be connected to relatively short subscribers' lines, reflection may occur at different points along the line, and may vary when the trunk line is connected to different subscribers' lines. There seems to be no way of calculating all possible conditions to permit adapting the circuits to substation apparatus. A patented arrangement for remedying this difficulty is what is known as the **terminal taper,** in which the inductance of the loading coils in the line is reduced gradually from the inductance corresponding to sections of the loading line to a low amount, so that, as there is no abrupt change, the reflection does not occur or is at least very much reduced. What takes place in a line circuit may be compared with the effect produced on a sound wave on meeting an obstruction. If the surface of the obstruction is solid, the wave is reflected sharply; if, however, the surface is yielding—such, for example, as felt, which is soft and capable of vibrating somewhat—so much of the sound wave is not reflected and hence it suffers less loss in the direction in which it is moving.

RESULTS OBTAINED ON LOADED TELEPHONE LINES

28. "Loaded Telephone Lines in Practice" was the subject of a paper presented by Dr. H. V. Hayes at the International Electrical Congress at St. Louis in 1904. From this paper, the following interesting and useful information is abstracted. It is here intended to state briefly the results that have been obtained by the use of loading coils on many of the telephone circuits of the Bell companies. In every problem affecting the transmission of telephone waves over a line, there are two factors to be considered—the attenuation and the distortion of the waves. The loss of energy of the waves on the line must be kept at a minimum, and the several component telephone or voice waves must be transmitted without unequal relative impairment. The introduction of lumped inductance in the form of loading coils on a telephone line tends to increase the distortion by the possible unequal reflection at the coils of the component waves of different periodicities, and by the possible unequal attenuation of the several waves in passing through the coils.

29. Reflection Losses.—The mathematical work of Professor Pupin and Dr. Campbell showed conclusively that if several loading coils lay within a wave length on any particular loaded circuit, and the coils themselves were theoretically perfect, the circuit was distortionless. The spacing of the coils on a circuit in practice, therefore, depends simply on a determination of the highest periodicity that should be retained in the telephone waves in order to maintain the character of the voice waves unimpaired. It has been found convenient, in studying the spacing of loading coils, to determine the number of coils on each particular circuit that would be passed by some one point of a wave in a second. As the velocity of all waves on a given circuit is the same, and as the wave length for any periodicity can be readily determined from the velocity, which is equal to

the periodicity multiplied by the wave length, it is possible to determine the number of coils lying within any particular wave length.

A large number of long telephone circuits have been equipped with loading coils, the spacing of the coils on the several circuits being such as to produce a range of the number of coils per second between 13,000 and 7,000. A comparison of the transmission over the several circuits has shown that the quality of transmission is not appreciably impaired, even with the lower number of coils per second—an arrangement that tends to weaken most waves of very high frequency. This seems to indicate the lack of importance of the overtones of very high frequency in the successful transmission of speech.

It can be said, therefore, with considerable certainty that the distortion due to reflection losses in a loaded telephone circuit can be neglected, provided that the coils are so spaced along the line as to give at least 7,000 coils per second, and provided that this spacing of the coils is substantially uniform throughout the line.

30. Distortion in Coil.—To entirely eliminate distortion in a loading coil, it must be designed so that the effective resistance of the coil to all the essential periodicities of the telephone waves shall be the same. Such a coil is theoretical, and cannot be obtained in practice. A loading coil must possess a required amount of inductance, and to reduce attenuation it is imperative that the resistance be kept as low as possible. For low resistance, the wire used must be of copper of large size and the number of turns kept small. A reduction in turns can be most readily obtained by the use of iron for the core. If iron is used there will be losses in both the copper winding and the iron core. It is impossible to eliminate these losses, which vary for different periodicities, and tend to produce distortional losses in the transmitted telephone waves. By not using iron, certain losses can be eliminated, but the coil would then be larger and more expensive. Practical and commercial reasons demand

an iron-cored loading coil, provided that such a coil can be so designed that its use in a telephone circuit will not be productive of appreciable distortion.

To determine whether, in practice, there was appreciably more distortion introduced by loading coils having iron cores, as compared with those made entirely of copper, two circuits were equipped, one with iron-cored coils, and the other with copper inductance coils. The circuits were each about 1,000 miles in length. The coils used on these two circuits were spaced alike, and had the same inductance and, approximately, the same resistance. The impedance of the coil having an iron core was about 15.5 ohms at a periodicity of 2,000 per second, and that of the copper coil 11.8 ohms at the same periodicity. These circuits thus loaded were compared with each other with the greatest care, and no difference was apparent either in the character or the quality of the telephone transmission. These tests are again confirmatory of the fact that the suppression, or reduction, of the voice waves of the highest periodicities does not appreciably affect the quality of intelligibility of transmitted speech. This experiment was considered as demonstrating conclusively the possibility of the commercial use of loading coils having cores of iron.

31. Dimensions of Load Coils.—A discussion of the theoretical dimensions of loading coils for different classes of circuits may be found in Dr. G. A. Campbell's paper in the Philosophical Magazine for March, 1903. In practice, the size and cost of the coils are factors requiring serious consideration. For aerial circuits, where the size of the line wire is large, and consequently the resistance of the circuit small, it is of the utmost importance that the effective time constant $\frac{L}{R}$ of the coil should be made as large as is consistent with reasonable cost. Except in so far as the cost is affected, the size of the aerial loading coil is of no special moment, as the coils can be mounted singly on the poles. The time constant of a coil can be increased by enlarging its

size, but such increase in size increases its cost. The best commercial loading coil is, therefore, the smallest coil that will give the required inductance and the largest effective time constant.

Following the theoretical considerations as deduced by Doctor Campbell, the resistance of the coils that have been used on aerial circuits has been made 2.4 ohms. The design of the core, the permeability of the iron, and the subdivision of the iron and the copper have been made such that a loading coil has been produced having an inductance of .25 henry, a time constant of .048 second, at a periodicity of 1,000 periods per second, and a bulk of approximately 314 cubic inches. This coil is toroidal in shape, 10 inches in diameter, and 4 inches high. It has an effective resistance of 15.5 ohms at 2,000 periods per second.

Coils designed to be used on cable circuits in which the size of wire employed is much smaller do not require to be made of as low resistance as the coil above described; consequently, their size and time constant may be made much smaller. Large numbers of cable loading coils have been placed in service, their design varying with the character of the circuit on which they were used.

32. Reflection.—In the terminal apparatus at present used in telephony, or where there is a condition of non-uniformity in the character of the line, the telephone waves suffer a reflection that, in many cases, is effective in materially increasing the attenuation. This reflection is particularly pronounced at the point where an unloaded section of line is connected to a loaded section. The amount of reflection is greater according as the divergence from uniformity increases. Thus, a section having a large inductance per mile, when connected with a non-loaded section, exerts a larger reflective action than one having a small inductance per mile.

In practice, the effect of reflection is of considerable importance, particularly when the loaded section is not relatively long. Theoretically, these reflection losses may be eliminated by the use of a perfect transformer (repeating

coil) introduced at every point of non-uniformity in the line. Even could such a perfect transformer be made, its introduction on commercial circuits is open to practical objections, and, as a substitute, its equivalent, a terminal taper, which consists of a series of coils of varying inductance, has been employed. The arrangement of the several coils constituting the taper is such that a coil having an inductance somewhat less than that of the coils used on the loaded section is placed nearest the loaded line, a coil of inductance somewhat less than the first taper coil is placed next in order, and a coil of small inductance is placed nearest the non-loaded section, or the terminal apparatus. The spacing of the coils in the taper corresponds with that of the coils on the line of which it is to form the terminal.

33. Loaded Cable Conductors.—The results obtained on certain circuits are explained by Dr. H. V. Hayes. One circuit consisted of a cable having wires .03589 inch in diameter and about 96 ohms per mile of circuit. The mutual capacity between the two wires was .068 microfarad per mile; the inductance added to the circuit by the loading coils amounted to about .6 henry per mile. In Fig. 6 are shown the results obtained in tests on the above cable circuit with the telephones applied directly at the ends of the cables. Without the coils, the attenuation increased and the current received at the distant end decreased very rapidly as the length of the cable increased, as shown by curve *1*. With loading coils, but no terminal taper coils, the transmission was superior for lengths exceeding about 12 miles, but inferior for shorter lengths of the same cable when unloaded, as shown by comparing curves *1* and *2*. It will also be noticed that the initial current on the loaded circuit is about one-quarter of what it is on the unloaded circuit. Moreover, the quality of transmission on shorter lengths of the loaded cable under these conditions is much poorer than the transmission over similar lengths of the same cable unloaded. But for the longer lengths, the transmission is superior on the loaded to that on the same lengths of unloaded circuit.

If terminal tapers are employed at both ends of the loaded cable circuit, with the telephones connected directly to the tapers, the attenuation is shown by curve *3*. Here, again, it is seen that the initial current for the loaded cable provided with terminal tapers is considerably less than that on the unloaded circuit, and that the transmission on short lengths

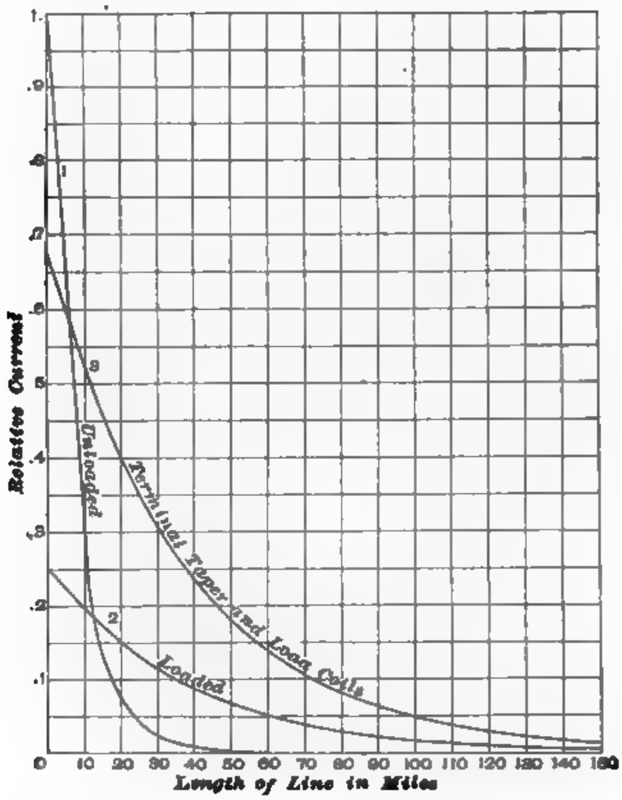


FIG. 6

of circuit is better on the unloaded than on the loaded cable with terminal tapers. But the introduction of terminal tapers on the loaded circuit has more than doubled the initial current on the loaded circuit, and has shortened by about one-half the length of circuit that previously showed the unloaded circuit to be superior. A cable, as shown by curves

1 and *3*, when loaded and supplied with terminal tapers, is superior to an unloaded cable for distances over about 6 miles. A comparison of curves *1* and *3* shows how great a factor the reflection losses are between the terminal apparatus and a loaded circuit, and the importance of the taper in reducing these losses. Bell engineers state that

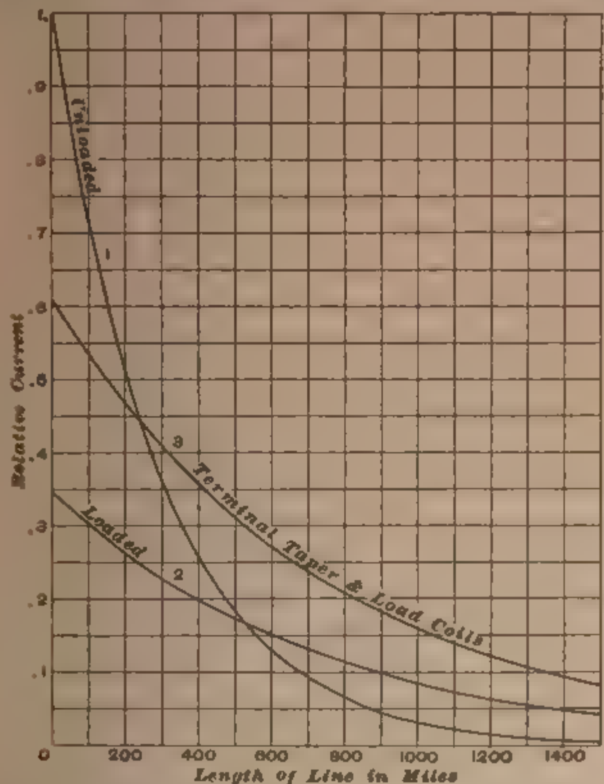


FIG. 7

in practice it has since been found that reflection losses can be still further reduced and under special conditions almost, if not entirely, eliminated; but how this is done has not been explained by any of them.

Similar tests and curves were made for a cable less heavily loaded, the inductance being brought up to only .17 henry

per mile. The conclusion drawn was that the reflection losses are much less in the case of the lightly loaded cable than is the case in that having the heavier loading. In fact, for shorter lengths of cable the lighter loading is more effective in transmitting the telephone wave than the heavier;

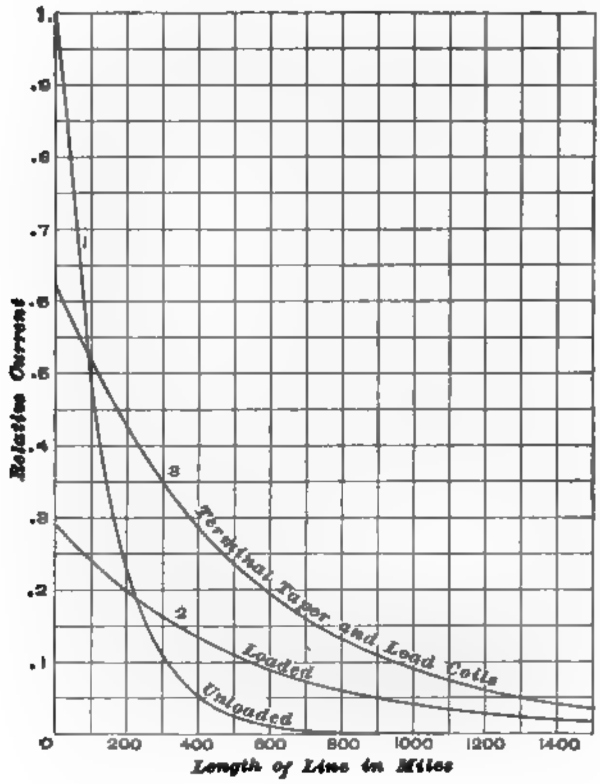


FIG. 8

for longer lengths, however, the heavier loading gives better results.

34. Loaded Aerial Circuits.—Results obtained on circuits of bare copper wire are represented in Fig. 7 for wire weighing 435 pounds per mile, and in Fig. 8 for wire weighing 176 pounds per mile. In each case, the circuit was loaded with coils that added about .1 henry per mile.

The results resemble those already explained for cable circuits. There is a large reflection loss, which is considerably reduced when tapers are employed. Even with tapers, the loaded line for short distances is inferior to the unloaded.

35. Doctor Hayes's conclusions are about as follows: In the case of cables, there is a distinct improvement in the quality of transmission produced by the introduction of load coils, the voice of the speaker being received more distinctly. The high insulation that can be maintained, at all times, on cable circuits renders it possible to introduce loading coils on circuits without danger of increasing the leakage losses. The marked diminution in attenuation, the improvement in quality of transmission, and the ease with which inductance coils can be placed on cable circuits without introducing other injurious factors, such as leakage or cross-talk, render the use of loaded cable circuits especially attractive.

The reduction of attenuation that can be obtained by the use of load coils on air-line circuits, even under theoretically perfect conditions, is less than can be obtained on cable circuits. This difference in the effectiveness of loading between the two classes of circuits, so far as attenuation is concerned, can be explained by the fact that on a cable circuit the capacity is large and the inductance of the circuit itself is practically negligible, due to the proximity of the two wires of the pair. On aerial circuits, on the other hand, the distance between the outgoing and the return wire is such as to make the capacity of the circuit much less, and its inductance much greater. This larger self-induction of the open-wire circuit operates to decrease the attenuation, and, as it were, to rob the load coils of part of their usefulness. Again, the insulation of an aerial circuit cannot be maintained as high or constant as that of a cable circuit, and the introduction of load coils on the line tends to increase the losses due to leakage.

Moreover, there is not the same improvement in the quality of transmission on a loaded aerial circuit, as compared with a similar circuit unloaded, as is found between loaded and unloaded cables. Initially, open-wire circuits are

practically free from distortion, whereas the distortion on cable circuits of long length is considerable. The addition, therefore, of load coils to aerial circuits cannot be expected to effect much improvement in the quality of transmission; whereas in the case of cables the introduction of the additional inductance renders the circuits practically distortionless, and effects a marked improvement in the clearness of the transmitted speech. It was rumored in 1905 that load coils on bare overhead lines were to be discarded as of not sufficient benefit to warrant their use.

36. Mr. John Gavey, chief engineer for the telephone department of the British post office, stated in 1905 that, by comparing a large number of results secured over lines of different character, the following rough empirical formulas were obtained to meet ordinary cases: For aerial lines of copper weighing 100 pounds or more per mile,

$$M = 210\sqrt{\frac{l}{1.75\,C\,R}} \qquad (1)$$

For unloaded paper cables,

$$M = 85\sqrt{\frac{l}{C\,R}} \qquad (2)$$

in which M is the limiting distance in miles over which a line having a capacity C and resistance R per mile of loop can be used for long-distance commercial conversation. By experiment and calculation these formulas were found to give reliable results within reasonable limits.

It has been shown that, in long-distance commercial conversation, each of the following is equivalent to 1,200 miles of No. 8 B. W. G., 425-pound aerial copper wire: 388 miles of 100-pound aerial copper line whose R per mile of loop = 17.73 ohms and C per mile of loop = .0078 microfarad; 560 miles of 176-pound aerial copper line whose R = 10.26 ohms and C = .0082 microfarad; 41.8 miles of No. 19 B. & S. (20-pound) American standard dry-core cable whose R = 88 ohms and C = .051 microfarad; 73.2 miles of the Boston-Lynn cable whose R = 41.8 ohms and C = .042 microfarad.

It has also been shown that each of the following is equivalent in transmission to 1 mile of 20-pound cable whose $R = 86$ ohms, $C = .055$ microfarad, and $L = .001$ henry: .61 mile of 10-pound cable whose R per mile of loop = 175.64 ohms, C per mile of loop = .055 microfarad, and L per mile of loop = .001 henry; 1.47 miles of 40-pound cable whose R = 42 ohms, C = .056 microfarad, and L = .001 henry; 1.83 miles of 70-pound cable whose R = 25 ohms, C = .063 microfarad, and L = .001 henry; 2.45 miles of 100-pound cable whose R = 17 ohms, C = .058 microfarad, and L = .001 henry; 2.95 miles of 150-pound cable whose R = 11.7 ohms, C = .065 microfarad, and L = .001 henry; 3.5 miles of 200-pound cable whose R = 8.75 ohms, C = .07 microfarad, and L = .001 henry; 8.45 miles of 180-pound aerial copper whose R = 18 ohms, C = .00808 microfarad, and L = .0039 henry; 14.7 miles of 200-pound aerial copper whose R = 9 ohms, C = .00862 microfarad, and L = .00366 henry; 26.1 miles of 400-pound aerial copper whose R = 4.5 ohms, C = .00919 microfarad, and L = .00344 henry; 45.8 miles of 800-pound aerial copper whose R = 2.25 ohms, C = .00987 microfarad, and L = .00322 henry.

REPEATING COILS

CONNECTION OF GROUNDED TO METALLIC-CIRCUIT LINES

37. It is frequently desirable, for several reasons, to connect grounded to metallic-circuit lines. This may be done by connecting them as shown in Fig. 9, where C is the central office, to which the two lines lead from station A and station B; c is a flexible conductor connecting one side of the metallic-circuit line to the grounded line, and c' another flexible conductor connecting the other side of the metallic-circuit line to ground at G. A complete circuit now exists from the ground at station A, through conductor c, one side of the metallic-circuit line, to station B, back to the other side of the metallic-circuit line, conductor c' to ground at G,

and thence to the ground at station *A*. A complete talking circuit is thus afforded, but this method of connection should not be used except where it is impracticable to make the connection otherwise. The fact that one side of the metallic circuit is connected directly with the ground completely destroys the balance of the metallic-circuit line, and thus renders it susceptible to all sorts of inductive noises from outside sources. Inasmuch as the metallic-circuit lines are usually long and the grounded lines local, practically all the desirable effects obtained by the metallic-circuit line are lost by this method of connection.

38. Repeating Coil Between Grounded and Metallic Lines.—The proper way to connect a metallic circuit to a grounded line is by the use of a repeating coil, which is merely a special type of induction coil. It is customary to make the primary and secondary windings of about equal resistance and number of turns, the resistance of each winding being in the neighborhood of 200 ohms.

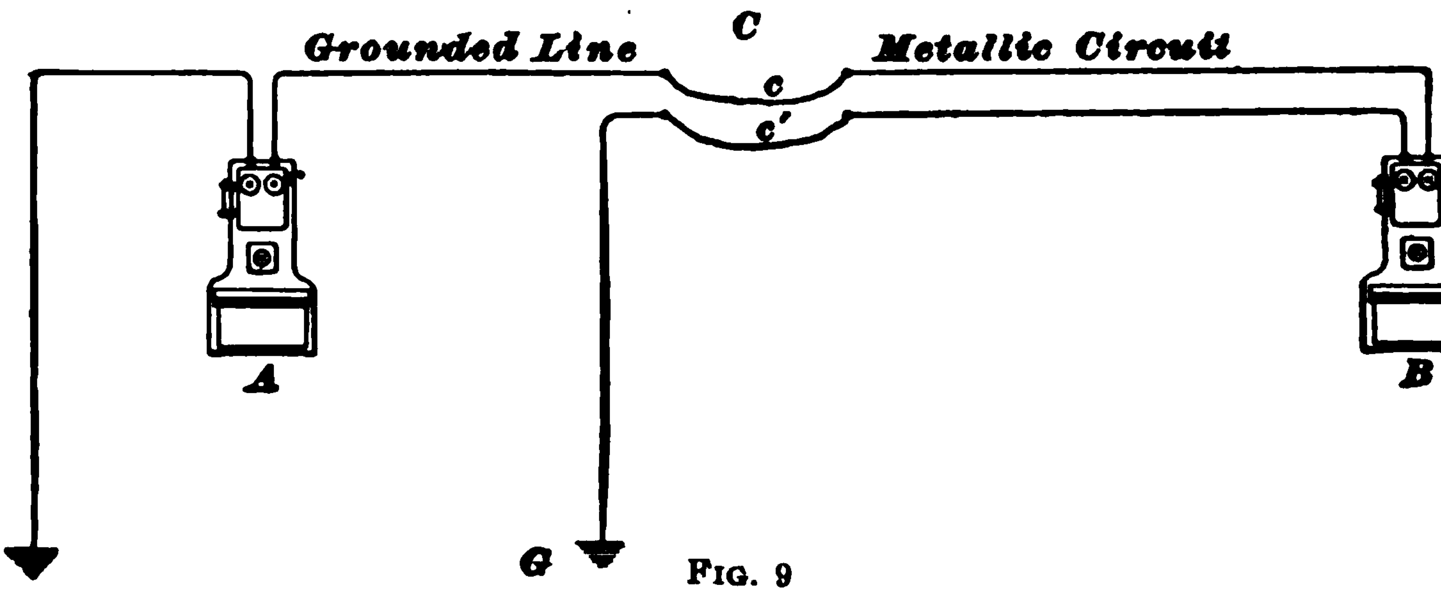


FIG. 9

One method of using a repeating coil is illustrated in Fig. 10, in which a metallic-circuit telephone line is connected through the repeating coil with a grounded line. The two terminals of the metallic circuit are connected, respectively, to two binding posts forming the terminals of one winding of the repeating coil. One terminal of the grounded line is connected to one terminal of the other winding, while the remaining terminal is connected to ground, as shown. When the telephone connected with the metallic circuit is transmitting, the winding of the repeating coil with which

the metallic circuit is connected acts as a primary, in exactly the same manner as the primary of an ordinary induction coil. It induces currents in the winding connected with the grounded line, which currents flow over the grounded circuit

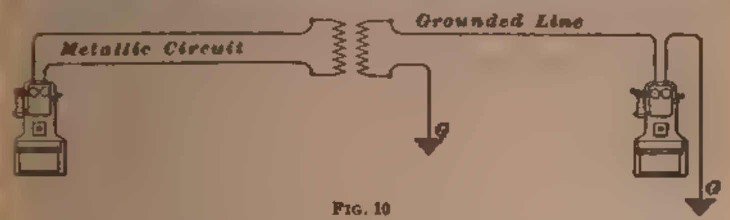


FIG. 10

and affect the telephone receiver of the grounded instrument in the ordinary way. When the grounded telephone is transmitting, the operation is exactly reversed, the winding connected with the grounded line serving as a primary and that connected with the metallic circuit as a secondary.

39. Advantage of Repeating Coils.—The great advantage of this method of connecting grounded to metallic-circuit lines over that shown in Fig. 9 is that the metallic circuit is kept free from metallic connections with grounded lines. Its balance is in no wise destroyed, and the induction from outside sources is only that which would ordinarily appear on the grounded line. There is an opinion among many telephone men that a repeating coil may be used in some mysterious manner to remove cross-talk, and, in fact, all kinds of induction, from telephone lines. This is a fallacy. If a line is subject to induction, the repeating coil will transmit this induction through it with as great an efficiency as it will transmit the voice currents. The proper way to get rid of induction on lines is to properly construct and transpose the lines. The repeating coil serves merely as a means for connecting dissimilar circuits without introducing new troubles on them.

However, it is sometimes possible by the judicious use of repeating coils to eliminate induction troubles. If a disturbing wire *a b*, Fig. 11, runs parallel and near a long grounded or common return circuit part of the way and

causes disturbing noises, the noises may be eliminated by using two wires for the telephone circuit where it is parallel to the disturbing circuit and connecting it to the two grounded or common return ends by repeating coils, as shown in the figure, and by properly transposing the metallic

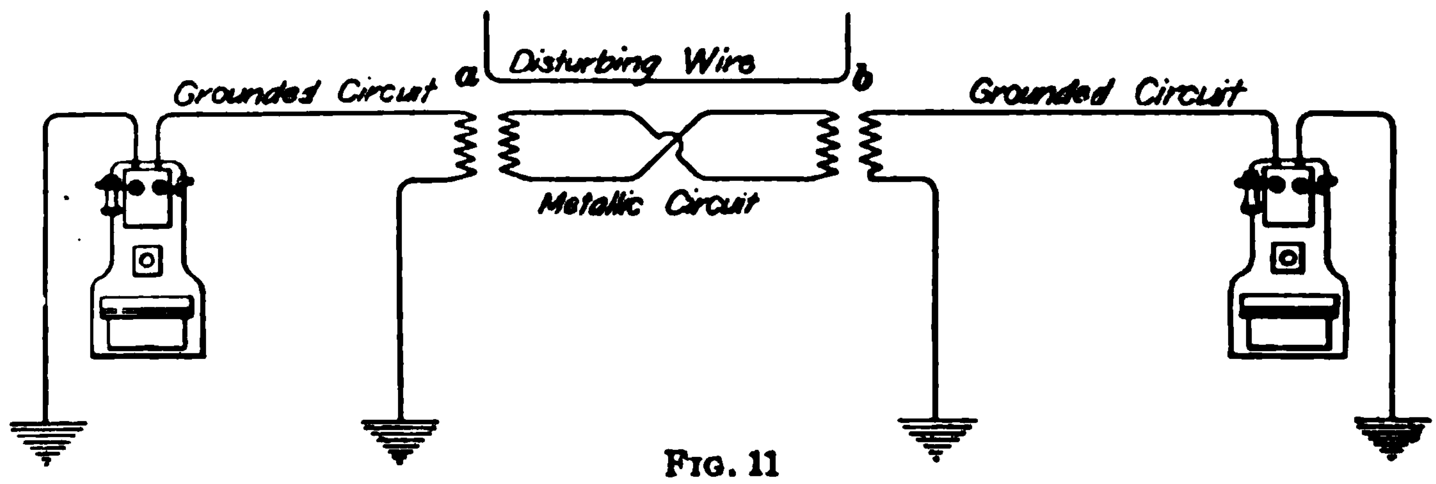


FIG. 11

portion of the telephone circuit. It will be more difficult to ring through the circuit on account of the presence of the two repeating coils, which should preferably be located at exchanges or switching stations, where they can be cut out, if necessary, while ringing.

DESIGN OF REPEATING COILS

40. Repeating-Coil Construction.—One method of constructing repeating coils is shown in Figs. 12 and 13, the former figure being a sectional view of the coil in an incomplete state, and the latter a view of the coil as finished. *C* is a core composed of small annealed-iron wires, held together by being slipped into a fiber tube *t*. On this tube are fastened three fiber washers, forming a spool on which the windings are placed. In order to make equal the effect of the two windings on the core and on each other, one-half of each winding is placed on each end of the spool; thus, one-half *A* of one winding is wrapped on the left-hand end of the spool, as shown; then the first half *B* of a second winding is placed on the right-hand end of the spool in the same manner. The second half *A'* of the first winding is then wound on top of the first half *B* of the second winding, and the second half *B'* of the second winding on top of *A*. One end of *A* is connected to one end of *A'* through the dividing washer of the

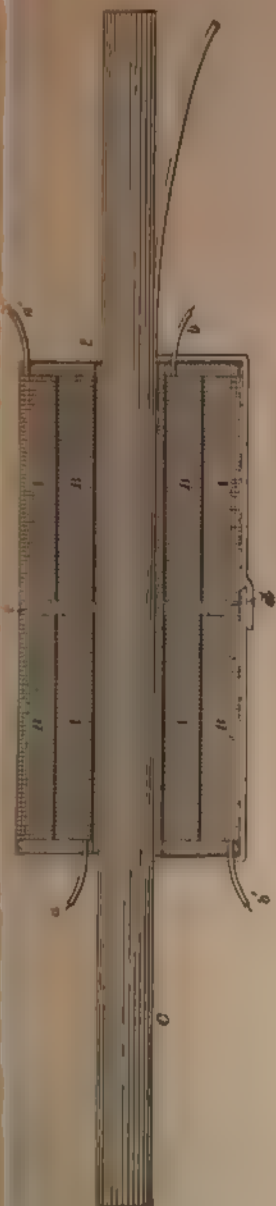


FIG. 12

spool, as shown at the point c. In a similar manner, one end of the winding is connected to one end of B through the dividing washer of the spool at the point d. The terminals of the winding $A A'$ are brought out at points a, a', while the terminals of the winding $B B'$ are similarly brought out at the points b, b'. After the winding is in place and properly covered with paper to prevent short circuits, the ends of the wires forming the core C are bent around the entire coil, as shown in the lower portion of the figure, so that the windings are entirely enclosed by the wires of the core. It will be seen that by this method of construction the magnetic circuit for the lines of force is made complete, and the transformation from the primary to the secondary is rendered more efficient. One of these coils in its finished state is shown in Fig. 13, it being fastened to a base block by straps of brass, as shown. The terminals of the two windings are brought out to binding posts arranged in any convenient manner on the base.

41. Ringing Coil.—The design of a repeating coil depends largely on the frequency of the primary current. The

electromotive force developed in the primary is proportional to the product of the number of turns on the primary, the number of lines of force, and the frequency. Hence, if the frequency is low, the number of lines of force and turns must be large to obtain the necessary electromotive force. If the number of lines of force is large, the cross-section of the iron core must be large to avoid magnetic saturation of the core. Hence, a low frequency requires a large repeating coil.

In order to be able to ring well through a repeating coil, the core should be short and much larger in cross-section than is required for a good talking coil, because otherwise the lower frequency ringing current would not

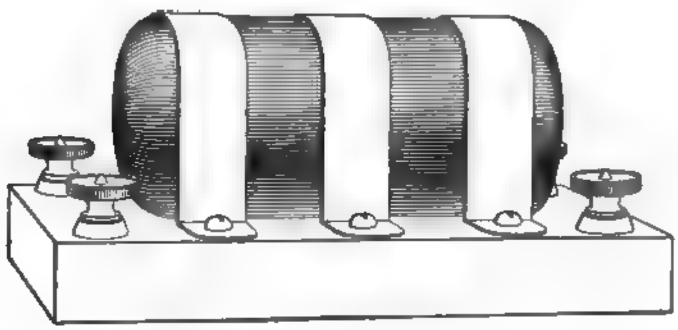


FIG. 18

induce sufficient electromotive force in the secondary winding for the work required.

42. Talking Coil.—Where a coil is to be used merely to talk through, the desired electromotive force can be obtained in the secondary with a small amount of iron in the core, because the voice currents, being very high in frequency, produce a high rate of change in the number of lines of force through the core. Furthermore, if too much iron is used in a talking coil, the hysteresis and eddy currents at such high frequencies reduce the efficiency more than is gained by the extra amount of induction produced. Hence, for talking purposes only, a repeating coil should be small in size, have a small iron core, and not a great number

of turns. It is not necessary for good transmission to have a closed magnetic circuit, but such coils are usually iron-clad to eliminate cross talk between neighboring coils. The most efficient talking coil is almost useless for the transmission of ordinary ringing current; and furthermore a large repeating coil, most efficient for ringing through, is not good for talking through; in the latter case the hysteresis and eddy-current losses in the large iron core become excessive, causing weak and inarticulate transmission of voice currents. To keep the eddy-current losses as low as possible, the core should be made of very soft, annealed, Norway iron, not larger than No. 22, and insulated by the oxide on its surface or by varnish.

43. Combined Ringing and Talking Coil.—As a rule, a coil through which it is necessary to ring must also be used to talk through, and, consequently, a good ringing coil must also be sufficiently good for talking purposes. Such a coil must have a sufficient amount of iron to make it efficient for ringing, and the core must be made of very soft annealed Norway iron, not larger than No. 22, in order that the hysteresis and eddy currents may not be excessive while talking. No. 22 or 24 iron wire is suitable for the core of almost any repeating coil. For the reasons given, a good ringing and talking coil is usually quite large and heavy, whereas a coil used only for talking may be quite small. Furthermore, coils used in central-energy systems must usually have much less resistance than coils that are inserted in other circuits merely to keep them balanced and quiet. No exact rules or formulas can be given for the design of repeating coils.

44. As already stated, the primary of a repeating coil usually has the same number of turns as the secondary, but sometimes, for special purposes, a different ratio is adopted. There are various ways, says W. A. Taylor, in the Electrical Review, of winding the coils in order to keep the turns and the resistance the same on each side. Fig. 14 shows a method commonly used: *a*, *b*, *c*, *d* represent four coils wound

on the iron wire core *e*. In this coil, *1* and *2* represent the terminals of the primary and *3* and *4* are the terminals of the secondary, the coils *a* and *d* forming the primary and *b* and *c* forming the secondary. In ordinary practice, both ends of each coil are brought out, as in some circuits it is necessary to connect into the middle of the primary or secondary. This form of coil is a good one for talking, but only fair for ringing. It is also quite expensive to make, for it is a very tedious piece of work to insert the wire core into the spools of wire and bend them around neatly. Where a number of these coils are placed side by side there is a great amount of cross-talk due to electromagnetic induction. For this latter reason and on account of the expense of manufacture, most of the coils now made are ironclad.

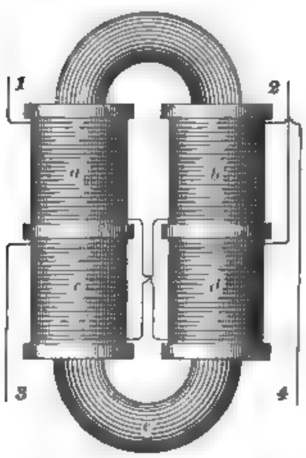


FIG. 14

These are of three kinds: First, those with a long core composed of a bundle of small iron wires that pass through the cylindrical spool of the coils and are bent back over the outside of the coils overlapping the two ends, as shown in Fig. 13. The second style is very much the same, except that the whole is covered with a piece of annealed wrought-iron tube, the ends of which are closed with iron disks (see Figs. 15 and 16). When the magnetic circuit is complete, the lines of force are confined to the iron, which offers them a return path of low reluctance. This is a very efficient construction, and has, moreover, proved necessary because of the amount of cross-talk caused by the former kind. The third kind has a straight core, which is only a trifle longer than the spool. This is placed in a tube, and end plates are pressed down closely against the ends of the core. This latter style is the cheapest form to make, and if properly designed will

perform its work very efficiently when used for either talking or ringing.

45. Fig. 15 shows also a form of winding adapted to the cylindrical repeating coil. Coils *a*, *d* connected together form one half, and *b*, *c* the other half. Should *a*, *b* form one of the windings and *c*, *d* the other, the resistance of the outer windings would be much greater than the inner, since each coil has the same number of turns. With one inside and one outside coil connected together, both the primary and the secondary are of the same resistance, provided that they have the same number of turns. In this coil, as in that shown in Fig. 14, all eight ends are brought out in order that it may be adapted to a number of circuits. This is the type of coil used by the Bell companies in their central-energy systems.

FIG. 15

FIG. 16

Fig. 17 shows another form of winding. On a straight core are wound the four coils *a*, *b*, *c*, and *d*, each of the same number of turns. The inner end of *d* is the one terminal of the primary; the outer end of *d* connects with the inner end of *a*. The outer end of *a* is the other end of the primary. The inner end of *c* is one terminal of the secondary and the outer end of *b* is the other end. The outer end of *c* and the inner end of *b* are

FIG. 17

connected together. With this arrangement of windings, both primary and secondary are of the same resistance, provided that each winding *a*, *b*, *c*, and *d* has the same number of turns of the same size wire. This coil is used extensively for central-energy work.

46. Some repeating coils are wound with two parallel wires, and some even with four parallel wires; in such coils, the wire must be double silk insulated. These last two methods should be avoided if possible, because the insulation between the two windings is very thin. Consequently, if there is too great a difference of potential between two windings that are adjacent throughout their length, due to lightning discharges or to neighboring high-potential circuits, there is very apt to be trouble due to the puncturing of the insulation, which is difficult to locate and repair. Sectional winding—that is, winding the coils on separately, either in two or four sections—is a much preferable method for most purposes.

The method of winding with four parallel wires is sometimes used where it is desired to make three telephone circuits from two metallic circuits, in which case it is necessary to have in each half of the primary and secondary exactly the same number of turns and resistance. In such cases, the two sides of the circuit must be balanced both for turns and resistance. It is rather difficult to wind such a coil neatly because of the four bunched wires.

COMMERCIAL REPEATING COILS

47. Following are the dimensions of some repeating coils made by some of the prominent telephone manufacturers in the United States. The first coil to be mentioned is wound as shown in Fig. 17. The diameter of the core is $\frac{3}{4}$ inch, made up of No. 26 annealed-iron wire, $14\frac{1}{2}$ inches long, and bent back over the spool after winding; insulation thickness between coils and next to core, $\frac{1}{32}$ inch of paper; length of winding space 5 inches and depth of winding space $\frac{5}{8}$ inch. Coil *d* has 2,700 turns and 26.7 ohms; coil *c*, 2,700

turns, 36 ohms; coil *b*, 2,700 turns, 45.5 ohms; coil *a*, 2,700 turns, 56.5 ohms. All sections are wound with No. 26 B. & S. single silk-covered copper wire. The primary has a total of 83.2 ohms and 5,400 turns; the secondary 81 5 ohms and 5,400 turns. This coil was made especially for ringing and showed great efficiency in that direction; it was also exceedingly good for talking purposes. This made a very large, heavy, and expensive coil; it also permitted cross-talk to a great degree, so that an iron shell had to be provided for it.

48. The following is a smaller coil that is just as good for talking purposes, but is 15 per cent poorer for ringing purposes than the coil just described. No. 29 B. & S. single silk-covered copper wire is used; length of winding space, 4 inches; depth of winding space, $\frac{1}{2}$ inch; diameter of core, $\frac{3}{4}$ inch, made of No. 26 annealed-iron wires $13\frac{1}{2}$ inches long, bent back over the outside. Coil *d* has 2,400 turns and 44.5 ohms; coil *c*, 2,400 turns, 55.5 ohms; coil *b*, 2,400 turns, 65.5 ohms; coil *a*, 2,400 turns, 75.5 ohms. The primary has a total of 4,800 turns, 120 ohms; the secondary, 4,800 turns and 121 ohms.

49. A coil with the windings consisting of four parallel wires has the following dimensions: length of winding space, 4 inches; depth, $\frac{1}{2}$ inch; diameter of core, $\frac{3}{4}$ inch; length of core wire $13\frac{1}{2}$ inches, made up of No. 26 annealed-iron wires, bent back and lapping over the outside of the coil. The number of turns of each wire is 2,000; resistance, 52 ohms of No. 29 B. & S. double silk-covered wire. The total resistance of primary and secondary is 104 ohms and 4,000 turns. This coil has a ringing efficiency about 20 per cent. less than that of the larger coil above mentioned and talked fully as well as the best.

50. The following coil is intended solely for talking, and gives the very finest results. It shows how much smaller a talking coil may be than one intended for ringing. This coil, which is also very efficient when used for central-energy purposes, has the following dimensions: length of winding space, 1 inch; depth of winding space, $\frac{3}{8}$ inch; diameter of

core, $\frac{3}{8}$ inch; length of core, $1\frac{3}{4}$ inches; size of core wire, No. 26 annealed iron; size of wire with which it is wound, No. 32 single silk-insulated. This coil is wound with concentric coils, as in Fig. 17. The coil *d* has 977 turns, 10 layers, and 22 ohms; coil *c*, 977 turns, 10 layers, and 31 ohms; coil *b*, 977 turns, 10 layers, and 37 ohms; coil *a*, 977 turns, 10 layers, and 45 ohms. The primary has a total of 1,954 turns, 20 layers, and 67 ohms; the secondary, 1,954 turns, 20 layers, and 68 ohms. After winding, the coil is slipped into an iron shell and the ends closed with iron disks. The total diameter of the shell is $1\frac{5}{8}$ inches and its length $1\frac{7}{8}$ inches.

It is, of course, not necessary to have an iron shell to cover the repeating coil, except where two or more are to be placed together closely. If the coils can be separated by a foot or more, the necessity for the shell disappears.

51. North Electric Repeating Coil.—The general appearance of a repeating coil for use on toll lines and common-battery supervisory systems, and made by The North Electric Company, is shown in Fig. 16. For full central-energy systems, lower resistance windings would be used, although the frame and general dimensions of the coil would remain the same. The armor on the outside is a piece of annealed wrought-iron pipe, having an external diameter of 2 inches, a thickness of $\frac{1}{8}$ inch, and a length of 6 inches, and the coil complete weighs $3\frac{1}{4}$ pounds. The core consists of a bundle of fine iron wires (about No. 28) that are firmly wedged against the iron plate forming the ends, by means of a wooden plug having wedges projecting into the bundle. There are four windings, two on each end of the spool, which is divided in the middle by a fiber washer. This division of the windings distributes them more equally in relation to one another and to the core, besides facilitating repairs. The construction of the coil is shown in Fig. 15.

Each of the four coils is wound to a depth of	$\frac{1}{4}$ inch
Space inside the case	$5\frac{3}{4}$ inches
Thickness of fiber heads	$\frac{1}{4}$ inch
Thickness of fiber middle division	$\frac{1}{8}$ inch

Diameter of fiber heads	$1\frac{15}{16}$ inches
Diameter of fiber core (outside)	$\frac{5}{8}$ inch
Length of winding spaces, each	$2\frac{17}{32}$ inches
Depth of each winding	$\frac{1}{4}$ inch
Average diameter of windings (outside coil)	$1\frac{3}{8}$ inches
Average diameter of windings (inside coil)	$\frac{7}{8}$ inch

Size of copper wire No. 30 B. & S. single cotton-covered insulation:

Number of turns in each layer of winding	160
Number of layers in each coil	18
Total number of turns, each coil	2,880
Number of feet in each winding (outside coil)	1,036
Number of feet in each winding (inside coil)	600
Resistance, each outside coil	107 ohms
Resistance, each inside coil	68 ohms

Fig. 18 shows the wiring plan of the coils. The two inside coils are connected together, forming one winding with

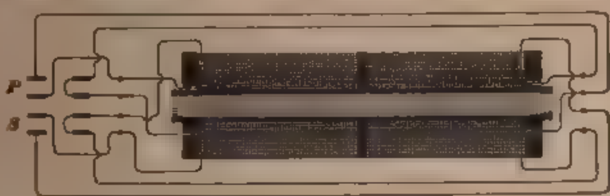
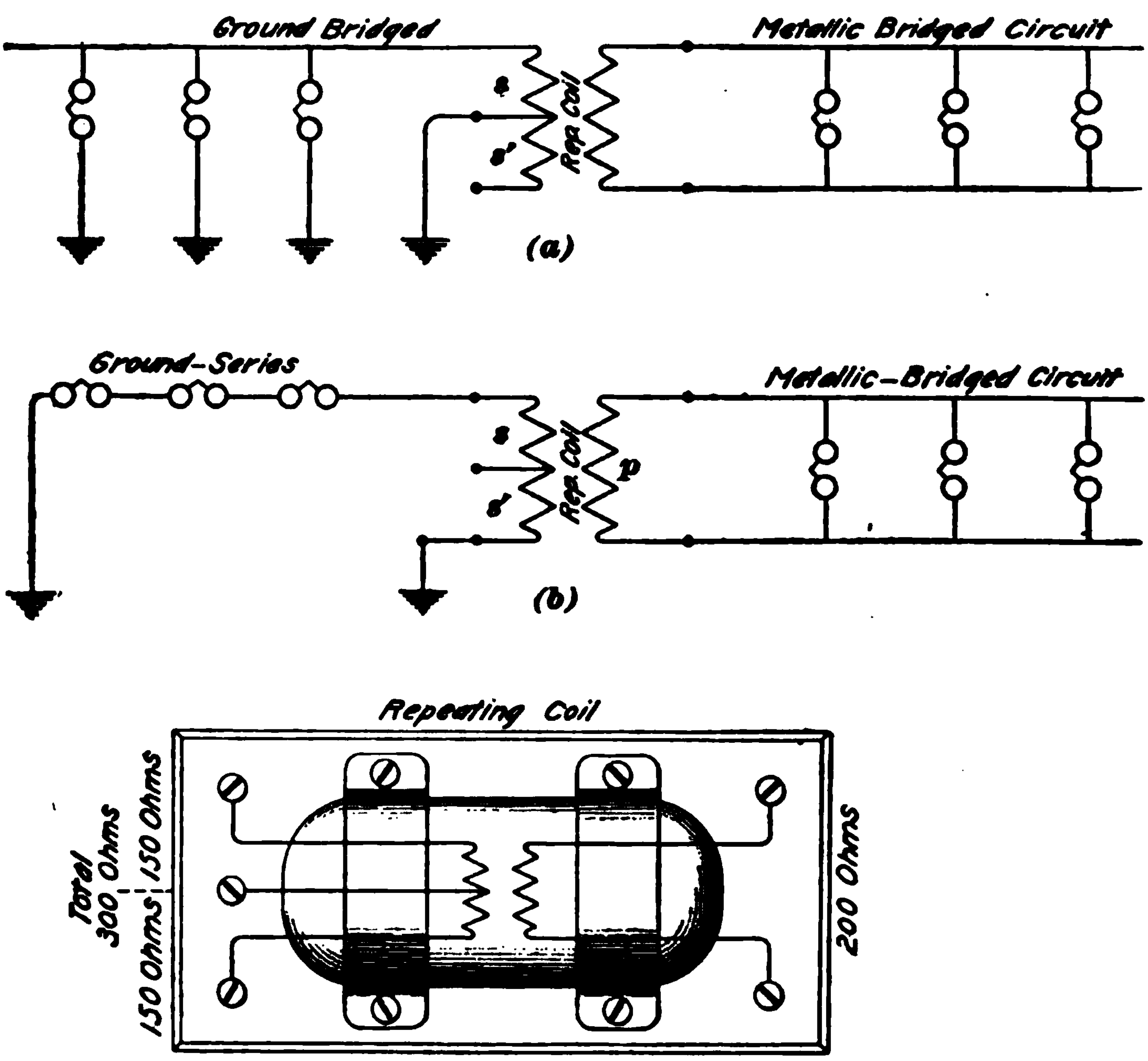


FIG. 18

terminals at P and the two outside coils together, forming the other winding with terminals at S. These coils can be made of equal resistance by connecting the outside coil on one end to the inside coil on the other end and the other two coils together, in which case both sides would have a resistance of 175 ohms.

52. Williams-Abbott Repeating Coil.—Special repeating coils are sometimes made for connecting metallic with grounded circuits. In Fig. 19 (*a*) and (*b*) are shown two ways in which the Williams-Abbott Co. direct their repeating coil, shown at (*c*), to be connected. At (*a*), the grounded bridged line is connected to only half the winding of one side of the coil, in order that the winding in circuit with the grounded

bridging bells may not have too high a resistance; otherwise too much of the talking current, originating in the grounded circuit, may escape to ground through the bridged bells instead of passing through *s*. It would seem preferable to connect *s′* (properly of course) in parallel with *s*, thereby halving the resistance of the winding on that side and still having the same number of efficient turns as when *s* alone is used. The connection of the two coils in parallel is



(c)

FIG. 19

equivalent to the use of one coil having the same number of turns as in *s* alone, but wound with a wire of twice the sectional area so as to have half the resistance of *s* alone.

With the arrangement shown at (*b*), the current is necessarily small and hence it is necessary to use all the turns available in series in the series-side of the circuit; moreover, the added resistance probably reduces the current very little because the relative increase in the resistance of the series-side,

due to the use of s', is small and is more than offset by the effect produced by the increased number of turns thereby obtained. As to whether either arrangement gives better results than would be obtained with coils of equal resistance

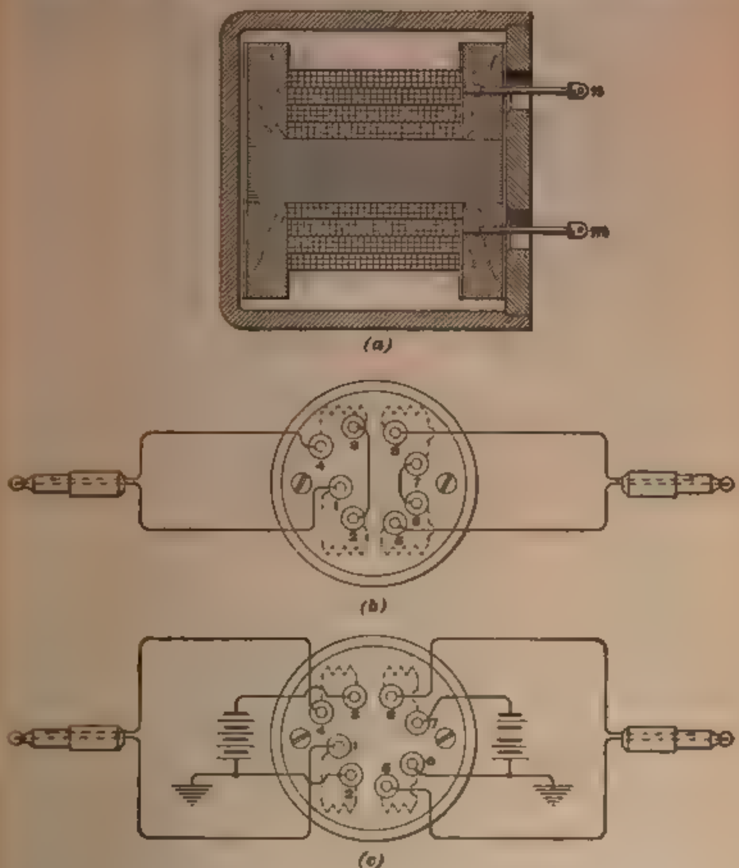


FIG. 20

and turns in each side, depends on which arrangement will give the maximum number of ampere-turns in the grounded side, which depends on the current strength as well as on the number of turns in each case. The slight stepping up of the voltage obtained from the bridging metallic to the

series-grounded circuit as indicated in (*b*), due to the greater number of turns in *s s'* than in *p*, would seem beneficial on account of the larger resistance of the series-circuit.

53. Kellogg Repeating Coils.—Two types of repeating coils are made by the Kellogg Switchboard and Supply Company; both are enclosed in iron shells to prevent cross-talk

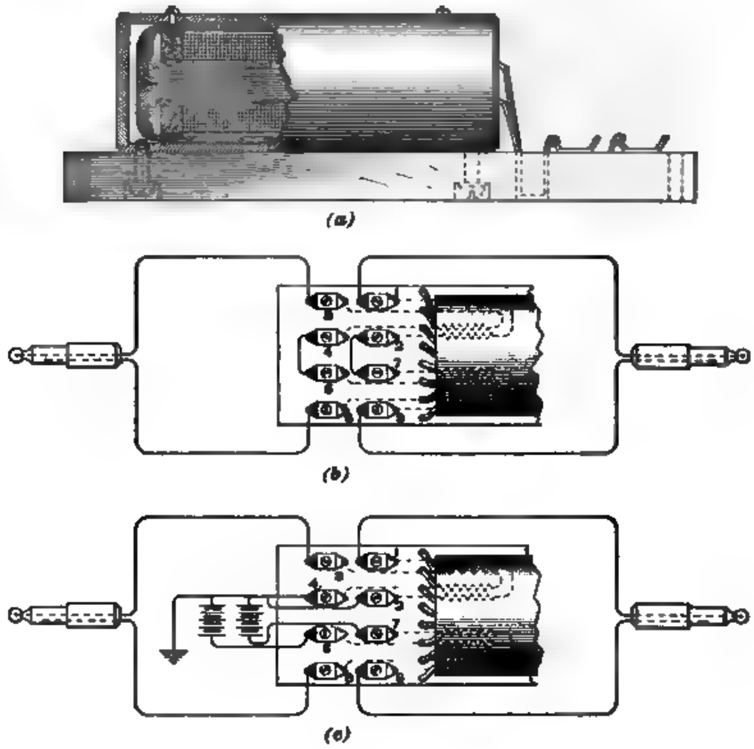


FIG. 21

between neighboring coils. The shells are copper plated and oxidized to prevent corrosion. The outside diameter of the coil is 1⅝ inches, and the length over all, including terminals, is 2⅞ inches. Fig. 20 shows a Kellogg No. 4 repeating coil, a type that has not enough turns or enough iron in the core for operating drops or ringers through it, and hence

is seldom used on magneto-switchboards; but it is especially suitable for use on toll lines through which talking efficiency is very essential. Eight terminals like *m*, *n* are brought out at one end of the coil.

Fig. 21 shows a Kellogg No. 5 A repeating coil, a type made for ringing through as well as talking. It is a compromise, or average, between the best talking coil and the best ringing coil. This coil is suitable for ordinary local-exchange work. Both coils have four windings, which are brought out to eight terminals, so that the middle points of the coils are available for various purposes. For regular service, where only two windings are required, the middle terminals can be connected together as shown in Figs. 20 (*b*) and 21 (*b*), thus combining two windings in each half of the repeating coil. Figs. 20 (*c*) and 21 (*c*) show how these same coils are connected for their central-energy system. Where a 1 to 1 ratio of transformation is required, the coil shown in Fig. 20 is provided with four windings of 1,357 turns each; the resistance of each half of the coil being 190 ohms; this coil is termed their No. 4 A. When wound to step-up the voice currents with a ratio of 1 to 2, so as to be suitable for toll or long-distance work, and termed No. 4 C repeating coil, terminal *2* should be connected to *3* and *6* to *7*. This will give the half of the coil between the terminals *1* and *4* a total of 1,950 turns and 53 ohms resistance, while the other half of the coil, between terminals *5* and *8*, will have 3,900 turns and 332 ohms resistance. The coil shown in Fig. 21, which is designed for both ringing and talking currents and adapted for use on all circuits requiring a combination coil, is provided with four windings of 2,400 turns each, the resistance of each half of the coil being 120 ohms. When coils No. 4 A or No. 5 A are used in local battery systems, connect together terminals *2*, *7* and also *4*, *5*. This brings the one half of the coil between terminals *1*, *8*, and the other half between terminals *3*, *6*.

MAGNETO-SWITCHBOARDS
(PART 1)

SMALL SWITCHBOARDS

1. **A telephone exchange** is a combination of a number of telephones, with their line circuits and switching devices, whereby any telephone may be connected, by means of the line circuits and the switching devices, with any of the other telephones, for the purpose of establishing communication between them. The ordinary form of exchange comprises a central office from which the lines or circuits of the various telephone users, or subscribers, radiate. These lines terminate at the central office in a more or less complicated switching device known as the *switchboard*.

The term **telephone system** is used to denote the organization of the exchange as a whole, and refers more to the arrangement of the various pieces of apparatus with respect to their circuits than to the actual construction of the apparatus, although this latter feature must conform with the circuits and arrangement of the parts, in order that each part may properly perform its function.

CLASSIFICATION OF SWITCHBOARDS

2. **Switchboards** may be divided into two general classes: *manual* and *automatic*. **Manual switchboards** comprise those in which the various operations needed to bring about a desired connection or disconnection between any two subscribers are performed manually by operators —usually girls. **Automatic switchboards** include those requiring no central-office operators, reliance being placed

on mechanisms at the central station, adapted to be controlled by the subscribers themselves, in order to bring about the desired connection and disconnection.

3. Either class may have primary batteries in local circuits at the subscribers' stations for operating the transmitters; such systems are termed **local-battery** systems. Or all sources of electrical energy may be located at the central exchange; such systems are termed **common-battery** or **central-energy systems.** Central-energy systems require no batteries or magneto-generators at the subscribers' stations.

When a manual local-battery system is provided with magneto-generators at each subscriber's telephone for calling up the exchange, it is usually called a **magneto-system.**

When the exchange, in a local-battery system, is called up by the mere removal of the receiver from its hook switch, and the disconnect signal is given by merely hanging up the receiver, it is frequently termed a *local-battery talking and common-battery supervisory system*, or simply, a *common-battery supervisory system*, or a *common-battery signaling system.*

Manual and automatic switchboards may be operated on the local-battery, common-battery supervisory, or central-energy system.

4. Exchange systems may have their line circuits arranged as *complete metallic circuits;* that is, two wires used throughout for each telephone circuit; or as *common-return circuits*, a common wire being used as a return for any number of telephones, to each of which one individual line wire is run; or as *ground-return systems*, in which one individual wire is run to each telephone and the ground is used as a common-return for all the telephone circuits. Although one wire may be, and formerly was, extended throughout the switchboard for common-return and ground-return systems, it is now no longer considered allowable; good practice now demands complete metallic circuits within the exchange building, even if the outdoor lines consist of common-return or ground-return circuits. Hence, but little consideration will be given to ground-return or common-return switchboards.

SWITCHBOARD REQUIREMENTS

5. General Operation.—In a manual switchboard, apparatus must be provided for attracting the attention of the operator when a subscriber desires a connection, means for enabling the operator to connect her telephone with the line of a calling subscriber in order to receive from him the order for connection, means for connecting his line with the line of the subscriber called for, means for calling up the latter subscriber, and lastly, means enabling either of the connected subscribers to attract the attention of the operator in order to inform her that the connection is no longer desired, or that they desire their lines connected with those of other subscribers.

6. Call-Receiving Device.—The device by means of which a subscriber is enabled to attract the attention of the operator at a magneto-switchboard is usually some form of electro-mechanical annunciator; this is termed a **drop** from the fact that, as ordinarily constructed, a shutter or target is

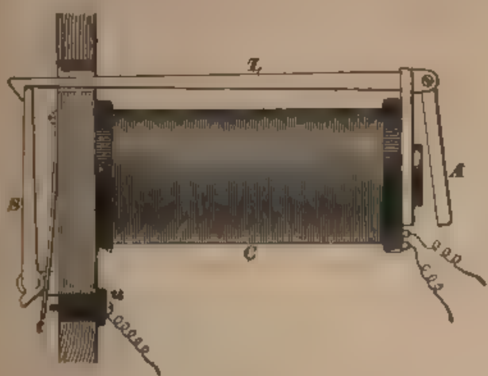


FIG. 1

allowed to fall in order to display a signal to the operator. It is released at the proper time by a current passing through its electromagnet when a subscriber operates his signal-sending device. One form of such an annunciator, or drop, is shown in Fig. 1, in which C is an electromagnet mounted

behind the front plate of the switchboard. *S* is a shutter pivoted near the lower end and normally held in its raised position by a catch on the end of the lever *L*. This lever is rigidly secured to the armature *A*, which is pivoted to an upwardly projecting plate from the rear end of the magnet spool, as shown. When a current is sent through the coil *C*, the armature *A* is attracted to the core, lifting the front end of the lever *L*, thus removing the catch from engagement with the shutter and allowing it to fall, and thereby displaying to the operator a designating number, either on the back face of the shutter *S*, or, what is more usual, on that portion of the front plate that is normally concealed by the shutter.

7. **Night Alarm.**—An auxiliary feature, known as a **night-alarm attachment,** is shown in connection with this drop. When the shutter falls, the spring *t*, which is made of very thin spring metal so as to be easily bent, is pressed into engagement with the contact pin *u* by the cam projecting from the bottom of the shutter. The spring *t* and contact *u* form the terminals of a circuit containing a battery and an ordinary vibrating bell; the bell is therefore sounded whenever a drop falls, unless the night alarm is open at some other point by a switch, which is usually the case during the daytime, when an operator is required to be constantly in front of the board, and therefore able to perceive visually the shutters as they fall. This night-alarm arrangement is therefore, as a rule, used only at night, when the exchange is not busy and when one operator is required to serve a larger number of lines than she could during the busy portions of the day.

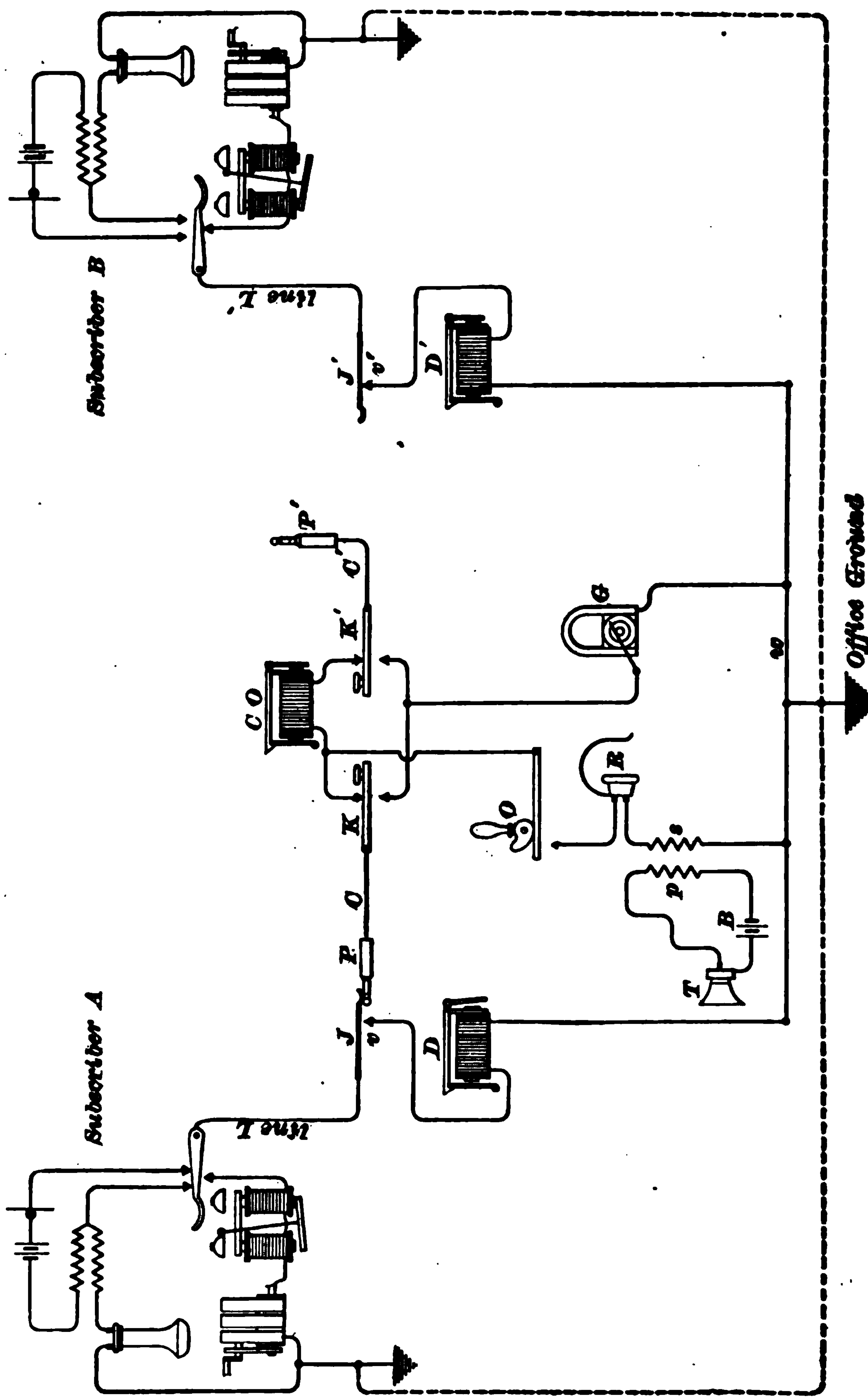
8. **Connecting Devices.**—The devices by which the operator is enabled to connect her telephone with the line of a calling subscriber, and to subsequently connect that line with some other line, consists of switches, termed spring jacks, and connecting cords terminating in plugs. The *spring jacks* are usually in the form of stationary sockets, which contain simple switching devices permanently connected with the subscriber's line circuit to which that jack

belongs. The connecting *plugs*, forming the terminals of flexible cords, are adapted to fit into the spring jacks and continue the circuit of the corresponding lines to the telephone of the operator or to the line of another subscriber.

SWITCHBOARD FOR COMMON-RETURN OR GROUNDED LINES

9. Circuits and Apparatus.—The circuits of one of the simplest possible forms of switchboard, including also the circuits of two subscribers' stations, are shown in Fig. 2. J, J' are spring jacks connected with subscribers' lines, as shown. The contact pin or anvil v or v' on each jack is connected, through the magnet of a drop D or D', to the ground, so that under normal conditions, as shown at J', the circuit of the line passes through the drop coil to ground; but when a plug is inserted, as shown at J, the connection through the drop is broken by lifting the spring of the jack out of contact with its anvil v. P, P' are the connecting plugs, attached by means of flexible cords to the levers of the keys K, K', respectively, which levers are normally pressed against their upper contacts by means of suitable springs, so that the circuit between them is normally completed through the coil of a drop CO, but by depressing either of the keys K or K', the corresponding plug is cut off from the other plug, and at the same time is connected with one terminal of a magneto-generator G, the other terminal of which is grounded. Connected to the upper contact of the key K is a lever that may be depressed by the cam O against a contact forming one terminal of the secondary circuit of the operator's equipment, including her watch-case receiver R and the secondary winding s of her induction coil. The other terminal of this circuit is grounded. The primary circuit, containing the battery B and the operator's transmitter T, is associated with the secondary circuit by means of the primary winding p of the induction coil.

10. Operation.—Suppose that subscriber A sends in a call by operating the generator of his telephone set and then



Subscriber B
Line L'
J'
v'
D'
P'
C'
K'
C O
G
w
Office Ground
E
O
K
Q
P
J
v
D
s
p
B
T
Subscriber A
Line L

FIG. 2

taking down his receiver. The operator will see the shutter of the annunciator *D* fall, and will at once insert the plug *P* into the corresponding jack *J* and restore the shutter of the drop *D*; this condition is shown in this figure. She then turns the cam lever *O* into such a position as to press its lever against the contact below, thereby connecting her telephone set between the line *L* and the ground. This circuit may be traced through line wire *L*–jack *J*–plug *P*–flexible cord *C*–key *K*–listening key *O*–operator's receiver *R*–secondary winding *s* –ground. The operator is thus enabled to converse with the calling subscriber, and learning that he wishes, we will say, to converse with subscriber *B* on line *L'*, she inserts plug *P'* into jack *J'* and presses down lever *K'*. This latter movement disconnects plug *P'* from the drop *C O* and plug *P*, and immediately thereafter connects it with the terminal of the calling generator *G*. This generator is usually constantly driven by an electric motor, so that a current at once flows from the generator through key *K'*–plug *P'*–jack *J'*–line *L'* –bell of the called subscriber to ground, thus calling him to his instrument. If subscriber *B* acknowledges the operator's call, she restores *O* to its original position, thus cutting out her own telephone set, and key *K'* being already released, the two subscribers are connected together for conversation through the following circuit: From ground at the station *A* –subscriber *A*'s receiver, secondary winding of induction coil and hook switch–line *L*–spring jack *J*–plug *P*–flexible cord *C* –key *K*–drop *C O*–key *K'* flexible cord *C'*–plug *P'* jack *J'* –line *L'*–subscriber *B*'s hook switch, secondary winding of induction coil and receiver to ground.

It will be noticed that the drop *C O* is included in this circuit connecting the two subscribers. This is called the clearing-out drop, and its function, as its name implies, is to convey a signal to the operator when either subscriber operates his generator, after conversation, to signify that a disconnection is desired, or that the subscribers wish their lines connected to other subscribers. When the shutter of this drop falls, the operator therefore again listens in the circuit by operating the key lever *O*, and if she obtains no

response from either party, concludes that the signal was for disconnection, and removes both plugs *P*, *P'* from the jacks. Although the clearing-out drop is in series with the line wires during conversations, its inductance is made low enough to avoid serious interference with the quality of transmission. When the operator listens on the circuit of two connected subscribers, her telephone is contained in a parallel circuit branching from the wire connecting the two subscribers to the ground. The current from the telephone of that subscriber who happens to be talking at any instant divides between the operator's and the other subscriber's telephone.

11. The jacks *J*, *J'* and their corresponding drops *D*, *D'* are shown removed from each other as though on separate boards; but this is done merely for the sake of clearness in diagrammatical illustration, and this system will be followed largely throughout this work. For further clearness, the flexible cords *C*, *C'*, connecting the plugs *P*, *P'* with the keys *K*, *K'* respectively, are represented by a straight line; in practically all switchboards having flexible cords and plugs, pulleys and small weights are used to keep each cord taut. A watch-case receiver *R* is found most desirable on account of its light weight and shape for operators' use, and is employed in nearly every central exchange.

12. Ground Connections.—All the circuits at the central office that are connected with the ground are first connected with a common wire *w*, which is itself grounded at what is termed the office ground. Each subscriber's instrument is also connected with the ground, as shown, and in this ground branch is normally included the magneto-generator and call bell, while the receiver is on its hook. When, however, the receiver is removed from its hook, the circuit is broken through the calling apparatus, but established through the talking apparatus, including the subscriber's receiver and the secondary winding of his induction coil. These circuits are the same as those described in connection with telephone instruments.

13. Ground on Common Return.—When a common-return wire is used instead of ground, the connection is made as shown by the dotted line; the ground at the subscriber's station is then omitted, except for the purpose of obtaining a ground for the lightning arrester. Many exchange managers prefer to ground the common-return wire at the central office, and, on the other hand, many equally competent managers keep the common-return wire free from grounds throughout the entire system. In some cases, undoubtedly, one plan might prove more desirable than the other, and as the experiment is easily tried, the proper method to suit any case can best be determined by actual trial.

SWITCHBOARD FOR METALLIC-CIRCUIT LINES

14. The switchboard so far described is suitable for either grounded or common-return lines. A switchboard to accommodate metallic-circuit lines is, however, of somewhat different construction, because connections must be provided for two wires for each line circuit, and also means for continuing the circuit from these two wires through the switchboard, in order to connect them with the two wires of another line. The signal-receiving device need not be different from that of the common-return or grounded line board, although the method of connecting it with the circuits is different. The jack and plug, however, must each be provided with two contacts instead of one; the two contacts in the jack forming, respectively, the terminals of the two sides of the line circuit, and the two contacts on the plug adapted to connect with the jack contacts when the plug is inserted. Each contact on a plug is normally connected to a similar contact on the companion plug through the means of a double-conductor flexible cord. The arrangement of the operator's talking circuits and also of the circuits of the calling apparatus follow the same general plan as that of the grounded-circuit system, but instead of connecting these various circuits between a single-cord conductor and the ground or common return, they are connected between the two conductors of the flexible cord.

15. Jack and Plug.—In Fig. 3 is shown a spring-jack arranged for metallic circuits, and also a double-contact plug, the two metallic portions of which are adapted to engage the contacts in the spring jack. In this jack, *s* is the metallic framework on which the various parts are mounted. Carried on, but insulated from this framework is the spring *t* that normally rests on the insulated pin *p*, to which is connected a metallic strip *c*. One side of the line circuit is connected with the metallic frame *s* by means of the screw *s''*. The other terminal of the line is connected with the rear projection of the spring *t*; while the rear projection of the strip *c* is connected with one terminal of the winding of the line drop, the other terminal of which is connected to the frame of the jack at *s''*. The plug *P* has an insulated handle and two

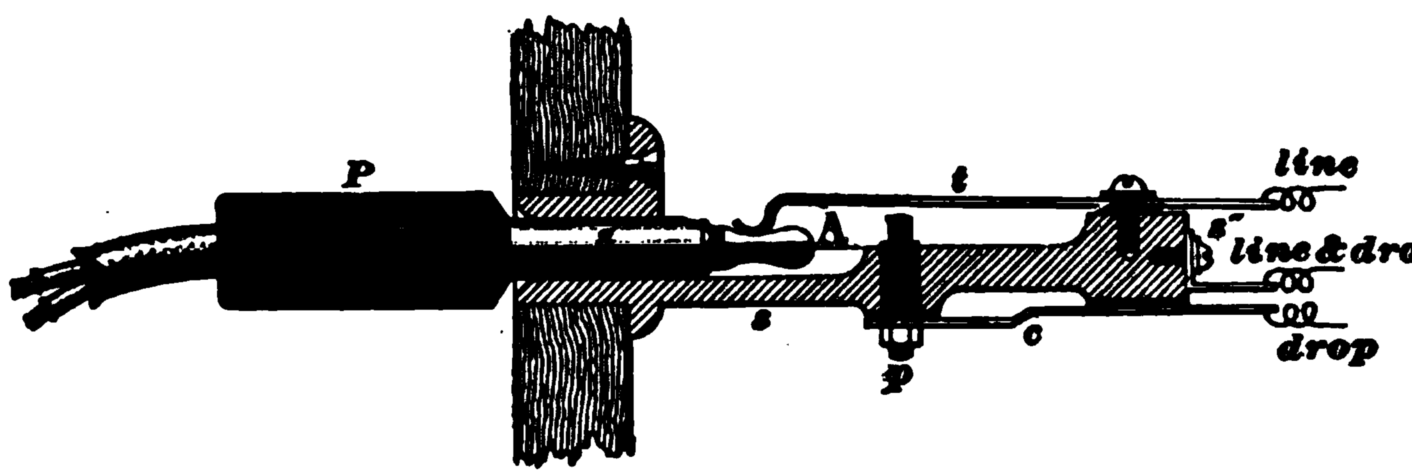


FIG. 3

metallic contacts *A* and *s'*, to each of which is connected, on the interior of the insulated handle, a terminal of one of the conductors of a flexible cord. The contact *A* is termed the *tip*, while the contact *s'* is termed the *sleeve*, of the plug, the latter surrounding the former, but carefully insulated from it by means of a tubular bushing of hard rubber or similar material. The conductor of the cord circuit that makes contact with the tip of the plug is usually designated as the *tip strand* of the cord, and the conductor making contact with the sleeve of the plug is termed the *sleeve strand*. For similar reasons, the contact spring *t* in the jack is termed the *tip spring*, while the contact *s* with which the sleeve of the plug engages, in this case the metallic frame of the jack itself, is called the *sleeve contact*, and the two sides of the line are frequently termed the tip and sleeve conductors, respectively.

16. Line and Test.—Another way of designating the two conductors of the line circuit and their respective contacts is to speak of that conductor which is connected with the spring *t* as the **line**, while the other side is termed the **test.** The reason for this designation will be understood when multiple boards are discussed, but for the present the terms tip and sleeve will be adhered to.

When the plug is inserted into the jack, its tip makes contact with the spring *t* and raises it from engagement with the pin *p*, thus breaking the circuit through the line drop.

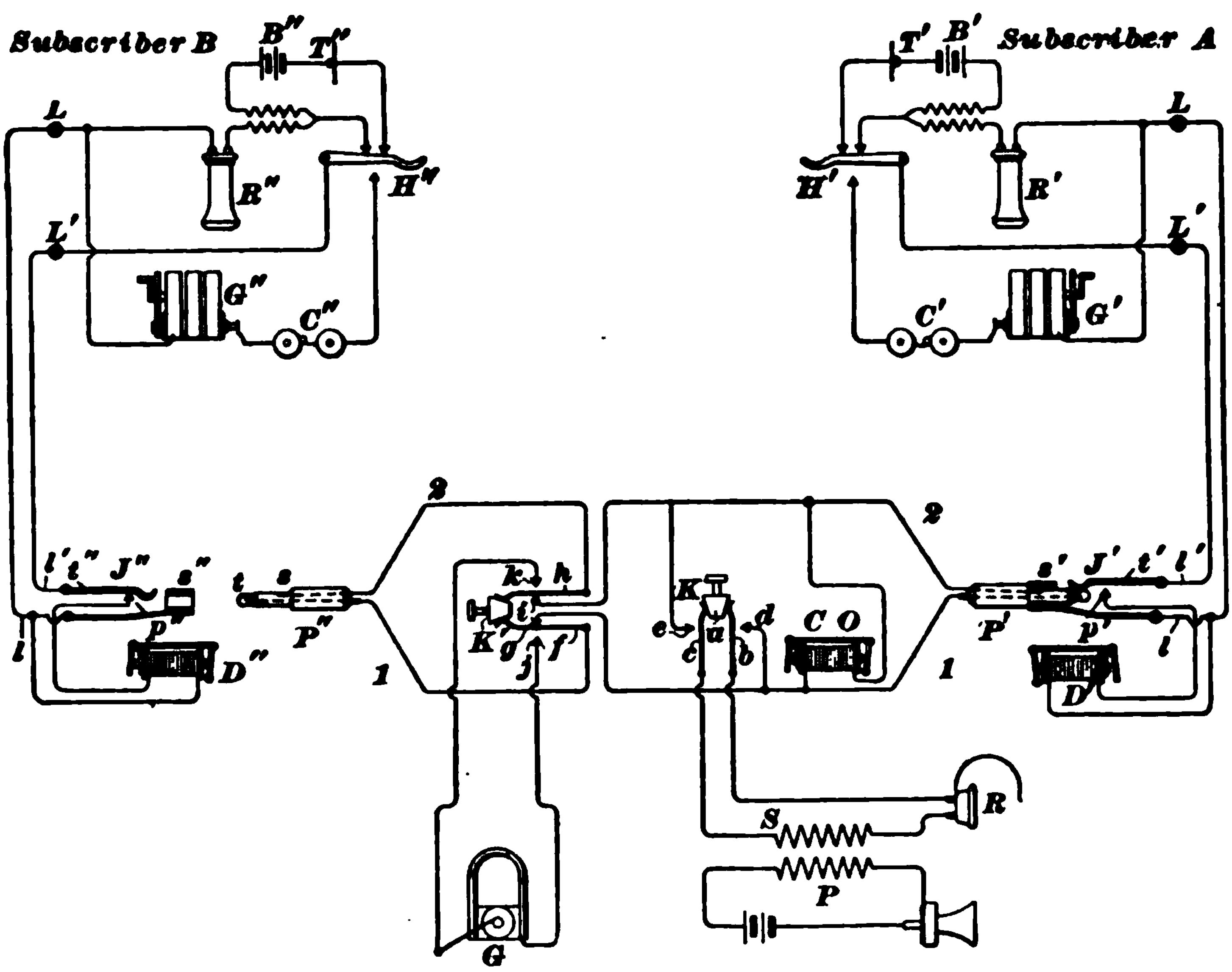


FIG. 4

17. The Line Circuit.—The circuits of a simple metallic-circuit exchange are represented in Fig. 4, in which J', J'' represent metallic-circuit jacks; s', s'', the sleeve contacts of the jacks; t', t'', the tip springs; p', p'', the anvils; and *t* the tip and *s* the sleeve of one plug. The line conductors l, l' are connected, respectively, with the sleeve and tip contacts, while the drops D' and D'' are, in each case, connected between the anvil and the sleeve side of the line. Under

normal conditions, as shown at J'', the drop is connected between the tip and sleeve sides of the line. The circuit, therefore, of a calling current coming from subscriber B, when there is no plug inserted in the jack J'', may be traced from the tip side l' of the line through the tip spring t'' -anvil p''-coil of the drop D'', belonging to B's line to the opposite side l of the line.

18. The Cord Circuit.—P' and P'' are termed, respectively, the *answering* and *calling* plugs, because P' is used to answer an original call and P'' for calling the subscriber wanted. The tips of the two plugs are connected together through the tip strand *1* of a pair of the flexible cords, while the sleeves are similarly connected by the sleeve strand *2* of the same pair of cords. The clearing-out drop CO is permanently bridged across the tip and sleeve strands of the answering plug side of the cord circuit. In order that this drop shall not form a circuit of too low resistance between the two sides of the circuit while connecting two subscribers together, the coil of the drop is wound to a high resistance, from 500 to 1,000 ohms. The impedance of the drop is still further increased by enclosing the entire winding in a tube of soft annealed iron, which tube forms the return portion of the magnetic circuit of the core, furnishing a path of low magnetic reluctance for the lines of force, and, therefore, with a given iron core, a given number of turns in the coil, and a given current, the total number of lines of force, and consequently the inductance will be a maximum.

From the formula

$$\text{Impedance} = \sqrt{R^2 + (2\pi n L)^2}$$

it is evident that the impedance will be much larger than the simple resistance R when both the inductance L and the frequency n are large, as they will be with this tubular form of drop during a conversation. While talking, the average value of n is about 300, but for the current from a telephone generator it is only about 14 to 20. The impedance of the drop is therefore much larger for the talking than for the generator current, and consequently sufficient of this

latter current will flow through it to drop the shutter, but practically none of the talking current can pass through it.

19. Ringing and Listening Keys.—The listening key K, when depressed, will connect the secondary circuit of the operator's telephone set across the two strands of the answering plug P', the action of this key being as follows: The conical wedge a, when pressed down by the button, presses the two springs b, c that form the terminals of the secondary of the operator's circuit against the stationary anvils d, e, which are connected, respectively, with the two strands of the answering cord.

K' is the ringing key, by which the operator may connect the terminals of the calling generator G with the two strands of the cord of the calling plug P''. Normally the tip strand 1 of the calling plug is connected with that of the answering plug by means of the spring f resting against the anvil g of the ringing key, and in a similar manner, the circuit between the sleeve strands 2 of the pair of plugs is maintained continuous by the spring h resting against the anvil i. When the key K' is pressed, however, the springs f, h are forced out of engagement with the anvils g, i and are pressed against the anvils j, k forming the terminals of the generator G. Thus, the operation of the key K' disconnects the calling plug P'' from the answering plug P' and connects the calling plug with the terminals of the generator G.

20. Calling Central.—The subscriber A, for the purpose of sending a call, operates his generator and causes his drop D' at the central office to display its signal. The operator, in answer to this signal, has inserted the answering plug P' into the jack J', thereby continuing the circuit of the subscriber's line to the cord circuit, and at the same time cutting out the drop D' by lifting the spring t' from the anvil p'. It is in this position that the apparatus is shown.

21. Listening In.—The next step on the part of the operator is to depress the key K, thereby forcing the springs b and c into engagement with the anvils d, e, and bridging her secondary circuit containing the head receiver R

and the secondary *S* of the induction coil across the cord circuit. She is enabled to converse with the calling subscriber in the ordinary manner, the circuit over which this conversation takes place being traced as follows: secondary winding *S* of the operator's induction coil–spring *c*–anvil *e*–sleeve strand *2*–sleeve of plug and jack *s'*–line wire *l*–binding post *L* of telephone *A*–receiver *R'*–secondary winding of induction coil–lever *H'* of the hook switch–binding post *L'*–line wire *l'*–tip spring *t'* of the jack–tip of plug *P'*–tip strand *1* of the cord–anvil *d*–spring *b*–operator's receiver *R*–back to the secondary *S*. This circuit is acted on by the operator's transmitter through her primary coil *P*, in the ordinary manner.

22. Making Connection.—Having learned that the subscriber *A* desires to be connected with subscriber *B*, the operator inserts the calling plug *P''* into the jack *J''* of subscriber *B*, thus cutting out his line drop *D''* and establishing connection with his line wires *l*, *l'*. She then depresses the ringing key *K'*, which connects the generator *G* directly across strands *1* and *2* of the calling cord, thus ringing the bell *C''* at the station of subscriber *B*. This calling current from the generator *G* does not pass to the station of the subscriber *A*, because in its action the key *K'* disconnected the plug *P'* from the rest of the circuit by breaking the contacts between *h*, *i* and *f*, *g*. It is not desirable to send the calling current from the switchboard generator to the station of the subscriber calling, because he is holding his receiver to his ear, and the generator current, in passing through it, will produce a violent noise, sometimes very painful to the eardrum and always annoying. For this reason, in good switchboards provision is made whereby the answering plug is cut off when the ringing generator is connected with the calling plug.

23. Talking Circuit.—When subscriber *B* removes his receiver from its hook, the talking circuit between the two subscribers is complete, and may be traced as follows: Secondary of the induction coil at the station of subscriber

B–receiver R'' at the same station–binding post *L*–line wire *l*–sleeve s'' of jack J''–sleeve *s* of plug P''–sleeve strand *2* of the calling cord–spring *h*–anvil *i*–sleeve strand *2*–sleeve of answering plug P'–sleeve s' of jack J'–line wire *l*–binding post *L*–receiver R'–secondary–hook lever H'–binding post L' –line wire l'–tip spring t'–tip of the answering plug P'–tip strand *1* of answering plug–anvil *g*–spring *f*–tip strand *1*–tip *t* of calling plug–tip spring t''–subscriber *B*'s line wire l'–binding post L'–hook lever H''–back to the secondary of his induction coil.

24. Clearing Out.—After the conversation is completed, one or both of the subscribers should operate their generators, or ring off, as it is usually termed. This will send a generator current over the line of the two connected subscribers, a part of which current will find a circuit through the clearing-out drop *C O*, and cause its shutter to fall. The operator, seeing the signal, should again depress the key *K* and inquire if the subscribers are through talking; if she receives no response, she will disconnect the lines by removing the plugs. If, however, one of the subscribers desires to be connected with still another subscriber, the operator may receive the order as before, and complete the connection desired.

SWITCHBOARD DETAILS

25. The two switchboards described are typical of a large number in actual use in the United States. They are never adapted, without certain important modifications, to exchanges having more than four or five hundred subscribers. Before describing the systems for handling a larger number of subscribers, the various parts of switchboards will be discussed, together with principles of their design. However, in some cases it will be better to describe the switchboard devices in connection with the switchboard with which they are used.

SWITCHBOARD DROPS

26. General Requirements.—Of **switchboard drops**, several important requirements must be taken into consideration. The drop must be so constructed mechanically as to always operate with certainty, even when the magnet is acted on by very feeble currents. In other words, the mechanical arrangements must be so designed that the shutter will be released by the least possible amount of energy imparted to the armature. The electrical design is no less important than the mechanical, and the point of greatest importance is the prevention, so far as possible, of the liability to short circuits or open circuits between the various convolutions of the winding of the core or framework of the switchboard, and also the prevention of open circuits due to the breakage of the wires. In order that the armature may be acted on to the fullest extent by the magnetism of the core, the magnetic circuit should, if possible, be so arranged as to present both poles of the magnet to the armature, so that the magnetic circuit will be practically closed by the armature when it is drawn toward the poles.

The armature should come as near as possible to the poles without touching them, and it is necessary to construct the core, the armature, and all portions of the magnetic circuit of the best grade of soft iron, so that there will not be enough residual magnetism to cause the armature to stick to the pole pieces after the current ceases to flow in the coil.

It is usually important, especially in the larger exchanges, to economize space, in order that the requisite number of drops and jacks may be placed in front and within reach of an operator. For this reason, the drops must be made small and mounted on the board with as little space between them as the mechanical and electrical conditions will allow. Each drop should, moreover, be readily accessible at all times, and be so secured to the board that it can be removed, in case of a breakdown, without disturbing the operation of the other portions of the apparatus.

27. Cross-Talk Between Drops.—The mounting of a number of drops in close proximity to each other introduces serious difficulty, which manifests itself in the form of cross-talk. This is true only in the case of drops that are included in the circuit of the line during conversation, as in the case of the clearing-out drops, and also in switchboards where the line drop is left in circuit for any purposes whatsoever. This is due to the induction between the coils of adjacent drops. For instance, when voice currents are passing over one line and through the drop in the circuit of that line, the coil of that drop acts in the same manner as the primary winding of an induction coil, setting up a varying field of force, which field reaches out so as to include the coils of the adjacent drops. In these coils, therefore, currents are induced which vary in unison with the currents in the coil of the first drop, and therefore conversation may be overheard on the lines having drops within the field of force of the first drop.

28. Remedies for Cross-Talk.—Three remedies may be suggested for the removal of this trouble: (1) the drop may be cut out of the circuit during conversation; (2) the

drops, if left in circuit, may be placed so far apart as to not affect each other; and (3) the magnetic circuit of the drop may be so arranged as to confine all the lines of force set up by the magnet within itself. The first of these remedies is possible only in the case of line drops, as the clearing-out drops must necessarily be left in circuit during conversation. They are usually of high impedance, and connected across the circuit and not in series with the line. However, it has been advantageous in some cases to leave the line drop in the circuit. The second remedy is usually not feasible, because of the lack of room on the switchboard. The third remedy is the one that is usually resorted to, and which, if properly carried out, gives excellent results. It involves the placing of the coil of the drop completely within a shell of soft iron, which forms in itself a portion of the path of the magnetic lines. The lines of force issuing from the core return through the soft-iron shell to their starting point, in preference to straying out and returning through the surrounding region.

29. Illustration of Cross-Talk Between Drops. In Fig. 5, A and A' represent the magnets of two switchboard drops taken from a switchboard and connected in circuits, as shown. Drop A is included in circuit with the secondary S of an induction coil, the primary P of which is

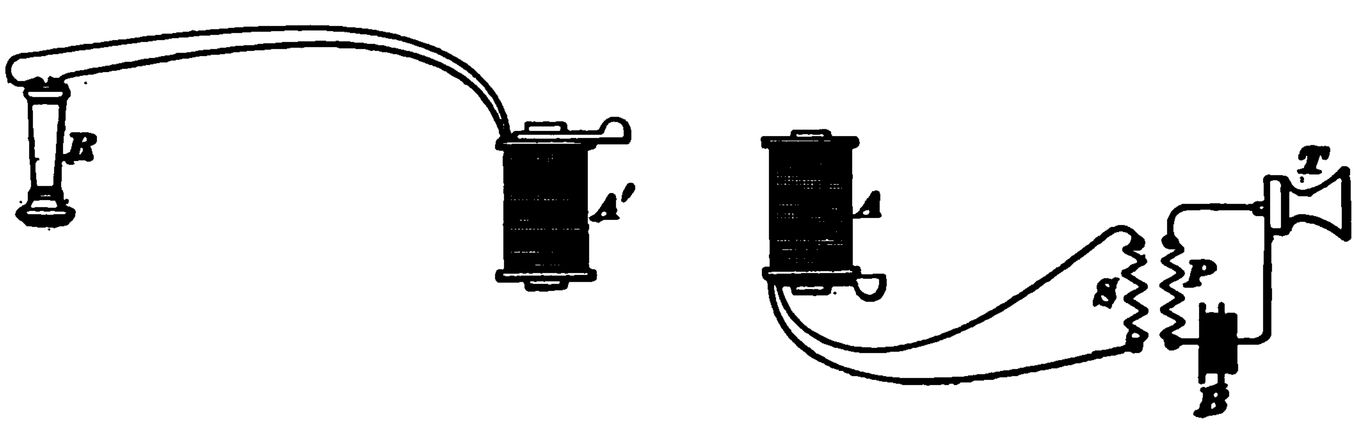


FIG. 5

connected in circuit with the transmitter T and the battery B. Drop A', which is entirely separated from drop A, is included in circuit with a receiver R. The transmitter and induction coil should be at such a distance from the two drops and the receiver as to render it impossible for the sounds uttered before the transmitter to be heard through

the air at the point where the drops and receiver are located. If a person holds the receiver to his ear and moves the two drops *A* and *A'* with respect to each other, he will find that in certain positions he will hear the sounds uttered before the transmitter very distinctly, even though the two drop coils are removed from each other by a distance of several inches. With an ordinary electromagnet, such as is shown in the drop illustrated in Fig. 1, it is often possible to hear these sounds in the receiver when the two drops are as much as a foot apart; while if the two drops be moved together, as they would be when in position on a switchboard, the sounds are so distinct that a conversation can be carried on without trouble.

30. It is probably the claim of all manufacturers that no cross-talk can exist between their switchboard drops. If the drops are cut out of line by the insertion of the plug, no further precautions need be taken in this respect on the part of a purchaser, but if the drop is left in circuit at all times, it is well to investigate this matter thoroughly. The test may be made by the method illustrated in Fig. 5, and great care should be taken that the conditions are the same as those that actually exist in the switchboard; and it is therefore well to make the test while the drops are actually in place on the switchboard. Unless drops are of the iron-clad type or are cut out of circuit, it is safe to say that cross-talk will exist to a more or less serious extent between them.

DIFFICULTIES WITH CLEARING-OUT DROPS

31. In magneto-exchanges, the clearing-out drop, if connected in series in the cord circuit, produces a distortion of the telephone current, due to the inductance of the coil; however, this makes a very reliable clearing-out drop. The distorting effect could be reduced by connecting a very high but non-inductive resistance, or, better still, a condenser not exceeding 2 microfarads capacity, in parallel with the clearing-out drop. If the clearing-out drop is bridged across the

cord circuit, its impedance is removed from the line, but the drop must be wound to a rather high resistance, and it is, therefore, not so responsive to signals from the subscribers, and complaints from the subscribers who ring the party to whom they have been talking, but fail to throw the drop at the exchange are not uncommon, because the lower resistance bell at the subscriber's station absorbs too much of the current, this being especially noticeable on short lines. The greatest difficulty with a clearing-out drop is, of course, the fact that the subscribers neglect to ring off when they are through talking, in spite of all that can be done by the exchange manager and operators.

To secure disconnection and a second connection on magneto-switchboards, with which both bridging and series telephones are connected, has been the cause of considerable annoyance and complaint due to the failure of the clearing-out drop to operate. Where a 1,000-ohm clearing-out drop is connected across the cord circuit, and a subscriber *A*, who has a bridging telephone, attempts to ring off by turning his generator when his circuit is connected to a series-telephone *B*, he usually finds that he has not been disconnected from subscriber *B* who is, therefore, summoned to the telephone a second time, and both conclude that the service is poor. The trouble is due to the fact that the clearing-out drop has failed to operate, because the 80-ohm series-bell at station *B* shunts too much of the current around the 1,000-ohm clearing-out drop. If both telephones *A*, *B* happen to be series-instruments, the same difficulty in ringing off will be experienced by each subscriber. Under these conditions, the only chance the subscribers have of securing a disconnection is by the constant supervision of the operator who listens in and says in the usual manner, "Waiting?" "Waiting?" "All through?"

REMEDIES FOR CLEARING-OUT DIFFICULTIES

32. Drop Shunted by Condenser.—There are several quite simple methods for reducing this difficulty. The first method consists in connecting a 1,000-ohm drop in series in

one side of the cord circuit, for instance, in the tip conductor, and connecting a condenser of 2 microfarads capacity in parallel with it. The 1,000-ohm drop will then be operated by the ring-off current either from a series or a bridging instrument, because the condenser offers relatively much greater opposition to the rather low-frequency ringing current than does the ring-off drop. The condenser will readily allow the voice currents to pass through it. One telephone may be bridging and the other series, or both bridging or both series instruments.

33. This method works satisfactorily in practice, but Mr. Lattig and Mr. Goodrum state in The American Telephone Journal that they consider the following method superior, claiming that it is more convenient and economical, and has, in addition, the advantage of having the clearing-out drop bridged across the circuit. This arrangement is shown in Fig. 6, in which *e f* and *h i* are non-inductive resist-

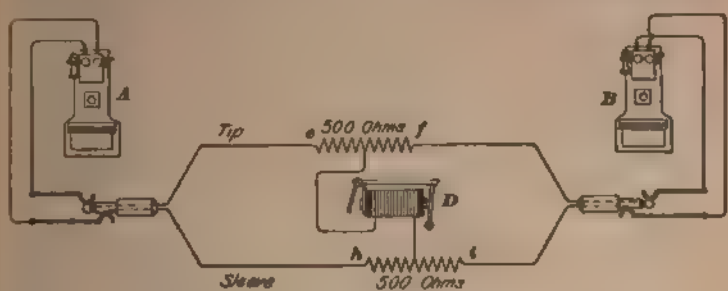


FIG. 6

ances of 500 ohms each, one being connected in the tip conductor, and the other in the sleeve conductor. The clearing-out drop *D* of 1,000 ohms resistance is connected from the middle of one resistance to the middle of the other. A bridging instrument *A*, even if connected through this cord circuit with a series-instrument *B*, can readily ring-off, because there will be at least 500 ohms resistance on the side of the cord circuit between *D* and *B*, and hence enough of the ring-off current will always be forced through the clearing-out drop to operate it. It is, moreover, immaterial

what resistance bell is used in the telephone *B*. With this arrangement, either telephone can readily ring off, whether one is bridging and the other series, or whether they are both bridging or both series instruments. Cords so equipped do not seem to give satisfactory results when connecting together two toll circuits, but no harm results from their use between local and toll circuits.

34. The Double-Wound Drop.—A somewhat different arrangement for a magneto-clearing-out drop, that, A. S. Siscom says, in The American Telephone Journal, has proved very satisfactory, is shown in Fig. 7. The drop has two windings, one of low resistance, 220 ohms, in series with the cord circuit, which makes it serve as a series-drop, and another of high resistance, 1,000 ohms, bridged across the cord circuit, which makes it serve as a bridged drop. The 2-microfarad condenser reduces the impedance

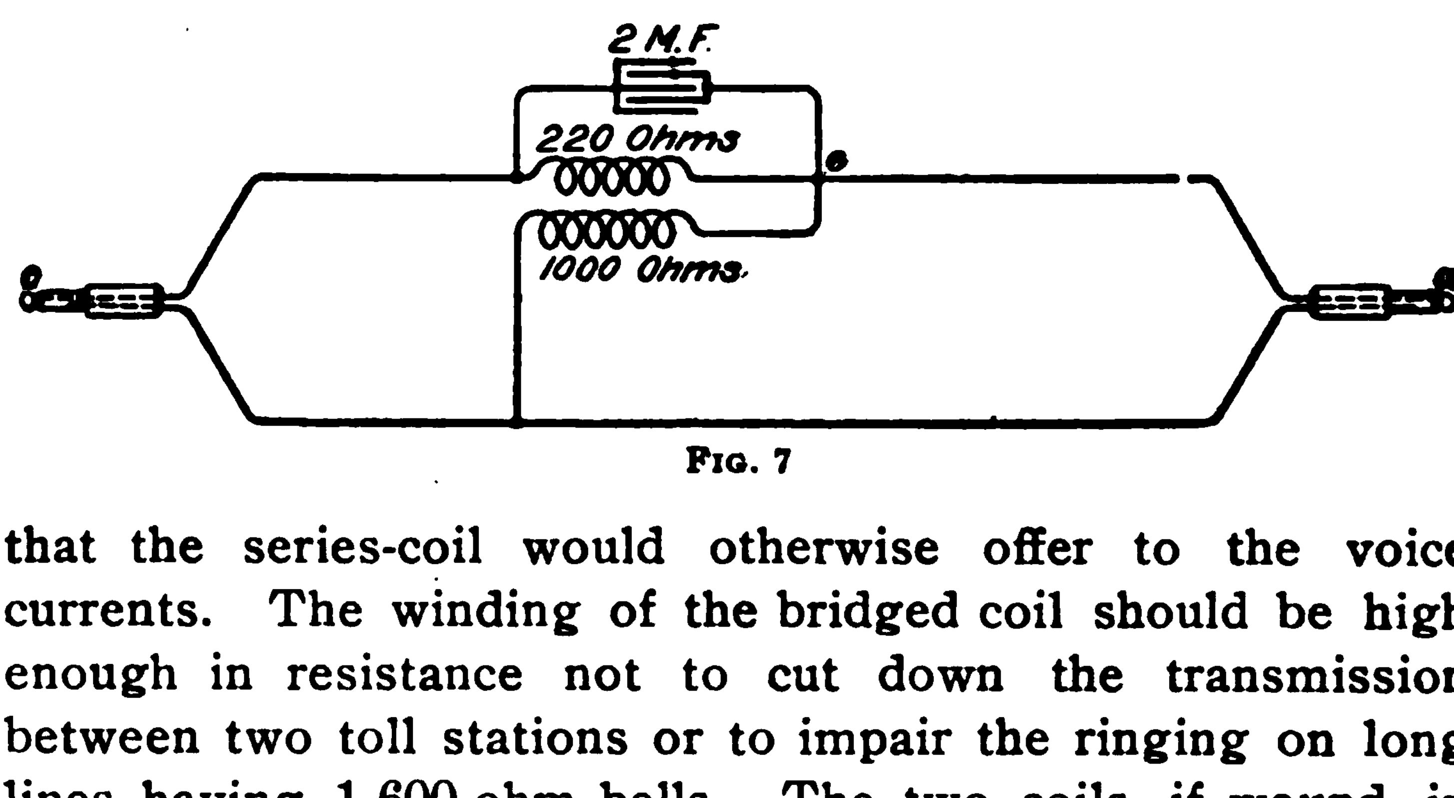


FIG. 7

that the series-coil would otherwise offer to the voice currents. The winding of the bridged coil should be high enough in resistance not to cut down the transmission between two toll stations or to impair the ringing on long lines having 1,600-ohm bells. The two coils, if wound in the same direction around the iron core starting from the common connection *e*, would not tend to neutralize each other for currents coming from *a*, but they would with currents coming from *c*, but not usually enough to seriously interfere with the action of the drop.

35. Clearing-Out Drop and Repeating Coil.—If a bridging drop is connected across a cord circuit in which a repeating coil is used, it will be nearly short-circuited by one

winding of the repeating coil. The best connections in such a case is shown in Fig. 8, in which a 2-microfarad condenser is connected in the middle of one winding of the repeating coil and a 500-ohm iron-clad clearing-out drop is connected across the condenser terminals. To a ringing current of 20 cycles per second, a 2-microfarad condenser has an impedance of about 4,000 ohms; and a 500-ohm iron-clad drop

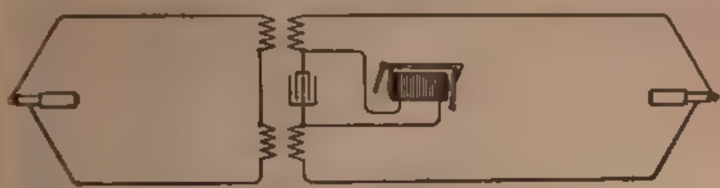


FIG. 8

having an inductance of 10 henrys has an impedance of about 1,330 ohms; hence, the drop will get about three-fourths of the total ringing current, which will be sufficient to operate it. But the impedance of the condenser will be very much less, about 260 ohms, to the voice currents, which have an average frequency of at least 300 periods per second, and hence such currents can readily flow through the circuit.

COMMERCIAL FORMS OF SWITCHBOARD DROPS

36. Mechanical Considerations.—From the statements given concerning the requirements of a drop, it will be evident that only the best possible mechanical construction can be used with success. In this connection, it may be said that the experience of the American Bell Telephone Company has proved that in the construction of switchboard drops, as, in fact, in all other classes of telephone apparatus, the best construction is none too good. Most independent manufacturing companies have learned this also, and are placing apparatus on the market that is capable of giving thoroughly satisfactory results.

In order to reduce the effort needed on the part of the armature in releasing the shutter, it is important that the catch that normally holds the shutter in position shall support

the shutter in a position where it has but a slight tendency to fall. This may be illustrated by reference to Fig. 1, in which the shutter, when in its raised position, is very nearly balanced on its pivots, so that it exerts but a very slight tendency to fall, and therefore exerts but a small pull on the catch of the lever *L*. This insures a minimum amount of friction between the catch and the shutter, which, therefore, reduces the pull required by the armature *A* to disengage the catch. In some forms, the movement of the catch in disengaging the shutter is in such a direction as to slightly raise the shutter against its weight before it can release it. This is a minor objection in some cases, but nevertheless one that should be avoided in designing a drop to attain a maximum degree of sensitiveness.

37. The drop shown in Fig. 1 is typical of a large class of switchboard annunciators, which are capable of giving good results when properly designed with respect to the mechanical and electrical conditions already pointed out. One objection to this drop is that it has no means of adjustment, and therefore no means of adapting it to long or short lines, or to weak or strong generators. Another objection is that the coil and the shutter are separately mounted on the panel of the switchboard. This panel is usually of wood, and therefore subject to changes in shape due to the absorption of moisture and also to the effects of heat and cold. This results in the alteration of the adjustment of the drop and frequently causes it to become inoperative. A good switchboard drop should have all its parts rigidly mounted on the same framework, and this framework should be of a material not affected by atmospheric changes.

It is about as satisfactory and cheaper to insulate the cores of drops, relays, and magnets with a hard-rubber tube, or other insulation superior to paper, rather than to insulate the metal part of these devices from the supporting framework, in order to avoid the danger of throwing together the lines or circuits connected to such devices that may become grounded on the core due to a lightning discharge.

38. Warner Tubular Drop.—In Fig. 9 is shown one of the most satisfactory switchboard drops yet devised. This drop, or slight modifications of it, is used in nearly all the American Bell Telephone Company's exchanges where electro-mechanical annunciators are employed. It is manufactured by the Western Electric Company, of Chicago, who make all switchboards for the above-named company. The

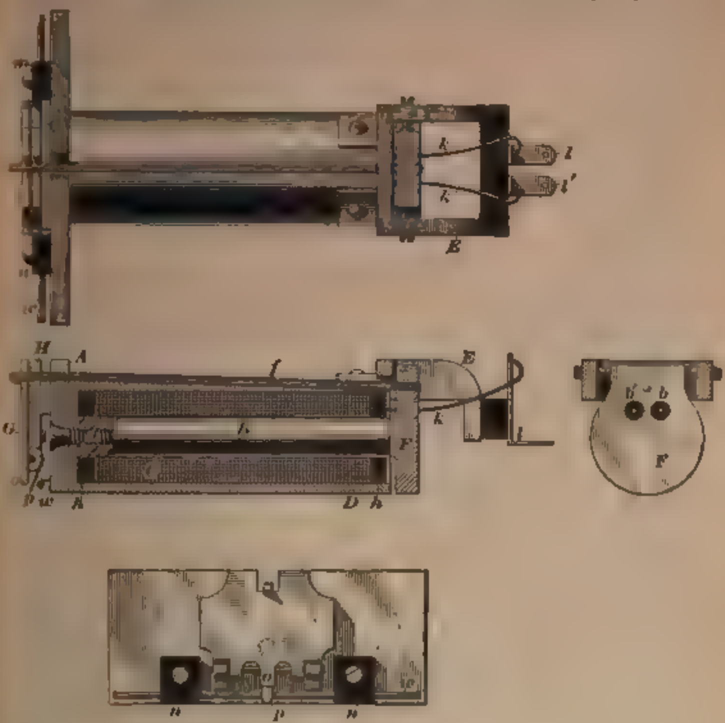


FIG. 9

coil C of the electromagnet is wound on a spool composed of a soft iron core B, properly insulated with paper, on the ends of which are forced two hard-rubber heads h. The coil is wound to have a resistance of about 500 ohms with No. 36 or No. 38 B. & S. single silk-covered wire. The coil, after being wound, is mounted within a tubular shell D composed of the finest quality of soft iron obtainable. This

shell is closed at its forward, and open at its rear, end, it being formed from a single piece of soft-iron rod bored out to the proper depth. This method of constructing it is much more expensive than it would be were the shell formed of a soft-iron tube having a thin cylindrical head driven in at one end; but the manufacturers have found that better mechanical and electrical results were obtained by the more expensive method, and have therefore adhered to it. This point is mentioned as illustrating the high-grade construction that is used in the best types of telephone apparatus. The tubular shell *D* is held against the front plate or panel *A* of the switchboard by means of a screw *a* passing through the forward end of the shell and into the core *B*, the screw thus serving not only to hold the shell against the front plate, but also to bind the core in its proper position within the shell.

On the rear portion of the shell is secured a bracket *E* of brass, within which is pivoted the soft-iron armature *F* carrying the forwardly projecting arm *f*. This armature, when attracted by the magnet, very nearly closes the tube, and therefore renders more complete the circuit of the magnetic lines set up by currents flowing through the coil. It will be seen that both poles of this magnet are presented to the armature, one pole being the end of the core itself, and the other the end of the shell that forms the outer path for the lines of force. On the front of the plate *A* is mounted a plate *H*, on which is pivoted the shutter *G*. A catch on the forward end of the arm *f*, which passes through a notch in the plate *A*, serves to retain the shutter in its raised position. The plate *A* is of iron and in the form of a strip, on which a desired number of drops are mounted, all the drops in one row being secured to the switchboard frame by means of the plate *A*, which is secured thereto at each end.

The terminals *k* and *k'*, leading from the coil within the shell, pass out through holes *b*, *b'* in the armature and terminate in clips *l*, *l'* mounted on the rear portion of the bracket *E*. In some cases, however, the extensions on the bracket *E* are omitted, the terminals being formed by means of stiff brass wires of about No. 16 gauge secured rigidly

within the rear head *h* of the coil and projecting through small slots in the iron armature for a distance of about ½ inch beyond the rear face of the armature. The terminal wires from the coil are soldered directly to these stiff brass wires, which in themselves form the terminals of the coil. In some cases, a night-alarm attachment is placed on these drops. The wire *w* mounted on the insulating blocks *n* forms one terminal of the night-alarm circuit, and is common to all the drops mounted on one of the front strips *A*. The other terminal of the night alarm is formed by the plate *H*, directly behind which is mounted the spring *p*. When a shutter falls, a downwardly projecting lug *o* carried on the shutter presses the spring *p* into engagement with the wire *w*, thus completing the night-alarm circuit in the same manner as described in connection with the drop shown in Fig. 1.

39. Complete Magnetic Circuit.—Many valuable points concerning the construction of drops may be gained by a consideration of the details of the one just described. The completeness of the magnetic circuit through the iron of the core, shell, and armature insures not only a maximum pull on the armature by the magnet, but also serves to confine all the magnetic lines set up in the coil within the iron itself, without allowing them to pass into the surrounding air to any appreciable extent. By thus destroying the external field that is ordinarily present in the air surrounding an electromagnet, the drop is rendered entirely free from any inductive troubles. So completely has this trouble been removed that under the most favorable conditions for induction, that is, when two drops are in actual contact side by side, no cross-talk or magnetic disturbance of any kind can be noticed between them.

40. High Self-Induction.—Moreover, by the presence of so much iron properly disposed in the magnetic circuit, the drop is given a very high inductance. While the actual resistance of the drop to steady currents is, as has been said, about 500 ohms, its inductance or impedance to rapidly alternating currents is several thousand ohms; and as a result,

when such a drop is placed in a bridged circuit between the two sides of a telephone circuit, there is no appreciable loss of efficiency in the telephone transmission due to the leakage through the drop.

41. Mechanical Advantages.—The adjustment of this drop cannot be affected by any atmospheric changes, because all the parts are rigidly mounted together, all the material connecting them being formed of iron or brass.

The lever *f* is attached to the armature *F* slightly below the pivotal points, in order that when the armature is moved toward the core the catch on the forward end of the rod *f* will be given a slight forward motion, at the same time that it is lifted, in such manner as to assist in disengaging itself from the shutter. The shutter itself, when raised, is in a position to exert but slight pressure on the catch on the rod *f*, and thus exerts a minimum amount of friction against the catch. All these points serve to make this one of the most efficient drops that has so far been devised.

42. American Electric Telephone Company's Tubular Drop.—Fig. 10 shows the tubular drop of the American Electric Telephone Company, in which the coil is

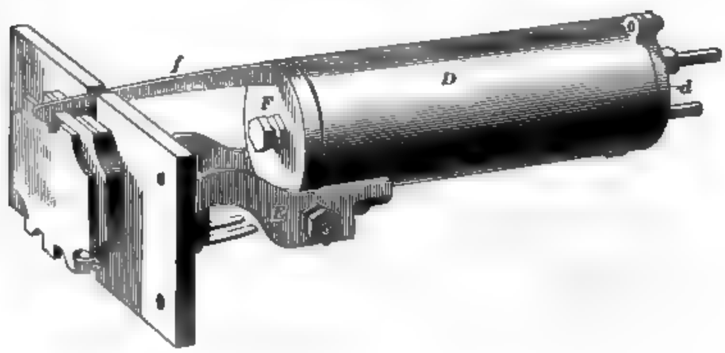


FIG. 10

enclosed in a tubular shield *D*, as before. This tube, however, is not made of one piece, its rear plate *d* being a separate piece screwed into position. The armature *F* carries a forwardly projecting arm *f*, and is pivoted at the points *e*

in a bracket E secured to the lower portion of the tubular shield. The forward end of this bracket is secured to the rear face of an iron strip forming the front of the board. The shutter is maintained in its raised position by means of a catch on the end of the arm f, in an obvious manner. In this drop, the shutter is held by the catch in a position for maximum efficiency, as in the Warner drop; but there is a slight disadvantage, due to the fact that in the attraction of the armature toward the magnet, the catch is pulled slightly to the rear before it lets go of the shutter, and is thus obliged to pull against the shutter before it can be released.

43. Of the large number of styles of switchboard drops, the tubular drop is undoubtedly the best, for it presents an almost perfect magnetic circuit, occupies but little space, and can be easily handled without danger of injuring the winding. The tube is of iron or, what is just as good, mild steel, the same material as is used for screws. It is generally bored out, but some firms are using drawn shells with great success. These latter make a first-class tube and are quite cheap, especially for the larger sizes. Where automatic boring machines are used and the size of the bore does not exceed $\frac{5}{8}$ inch, it has generally been found cheaper to bore the shells than to draw them. These shells, in either case, must be thoroughly annealed, and should have as great a diameter as is consistent with a reasonable sized switchboard, in order that a maximum sized magnet coil may be inserted. In general usage, the outside diameter of the tubes varies from $\frac{3}{4}$ inch to 1 inch, with a wall $\frac{1}{16}$ inch or $\frac{3}{32}$ inch The length generally approximates three times the diameter. The pivot screws are pointed and project into holes in the edge of the armature. These holes should be placed a little in front of the center line of the armature, that is, on the side toward the core, so that the armature will have a greater tendency to balance the hook rod.

44. Drops for Party Lines.—For party lines it is often necessary for the drop to make a considerable noise when actuated, in order that the operator may determine, by its

sound, whether the call is for her or for some other party on the same line. This is true in all cases where a code of signals is used to designate the particular station being called.

This proves very satisfactory when the switchboard operator is always in attendance, but in the country, where some member of a farmer's family or a storekeeper attends to the switchboard, it is often desirable to terminate these lines in a signal that will not only visually indicate the line, but will give a distinct audible signal, loud enough to be heard throughout the room. Sometimes a magneto-bell is placed in multiple with the drop at the switchboard, in order that the operator may receive the signal by ear as well as by sight; but as such a bell always reduces the efficiency of the drop to some extent, it is not advisible to do this, especially in the case of a long, heavily loaded line. By giving the armature of the drop a rather wide play, it usually makes a sufficient noise for the operator to distinguish between calls for some other party on the line and those for the switchboard.

45. Combined Audible and Visible Signal.—Combined audible and visible indicating devices are made for this purpose by many companies, differing more or less in

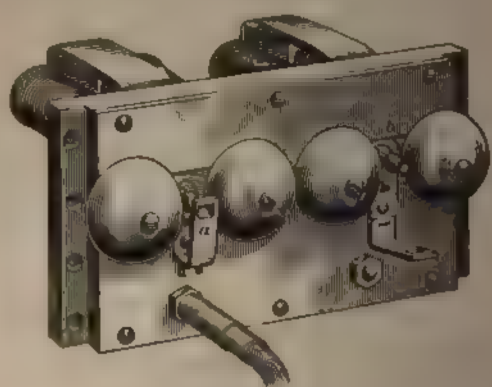


FIG 11

construction. The combined ringer, drop, and jack shown in Fig. 11 is made for this service by the Kellogg Switchboard and Supply Company. It consists of a standard

Kellogg long core ringer with two gongs and a latch drop indicator. The first movement of the bell hammer in either direction causes the catch *b* on the end of the bell hammer to release the shutter *a*, which then falls by gravity. If the operator hears the signal, she will know by the combination ring given whether her assistance to make a connection is required, and if so, the fallen shutter will indicate the line over which the call came. This drop is provided with night-alarm contacts, which can be wired to the regular night-bell circuit if desired. The jack mounted in connection with each ringer is of the same construction as that used in the Kellogg combined drop and jack, but is not provided with the self-restoring feature. The local contact spring in the jack is opened when a plug is inserted, thus cutting the ringer coils out of the line circuit.

JACKS

46. Economy of Space.—In the design of **spring jacks**, especially for use in large switchboards, the economy of space is an important consideration. This will be made more apparent when the subject of multiple boards is considered, for in those boards each operator must have within her reach a jack for every line in the exchange. For small boards, however, the question of space is not so important, as the number of jacks within the reach of the operator need not be so great.

FIG. 12

47. Two-Conductor Jack.—In Fig. 12 is shown a form of two-conductor jack similar to that shown in Fig. 3. The tip spring *t*, however, is held in place by the same screw *s* that forms the terminal of the line wire that connects with the frame of the jack. This screw passes through an insulated bushing, through the spring *t*, and into the metallic portion of the jack. The jack is held in place against the rear face of

the board *B* by means of a threaded bushing *C*, which passes through the board from the front, and engages a corresponding screw thread on the main portion of the jack. A slot is provided in the front of the bushing *C*, in order that the jack may be readily removed from the panel with a screwdriver.

48. The Double-Spring Contact.—It has been found unsatisfactory to rely on the contact between the sleeve of a plug and a tubular bushing, such as is shown in Figs. 3 and 12. In both of these figures, the connection with the tip of the plug, which is made in each case by means of the spring *t*, is reliable; but the contact between the sleeve of the plug and the inner surface of the bushing is likely to become loose and the surfaces dirty, so that a poor connection results. In Fig. 13 is shown a spring jack where both the tip and sleeve connections are made by means of springs.

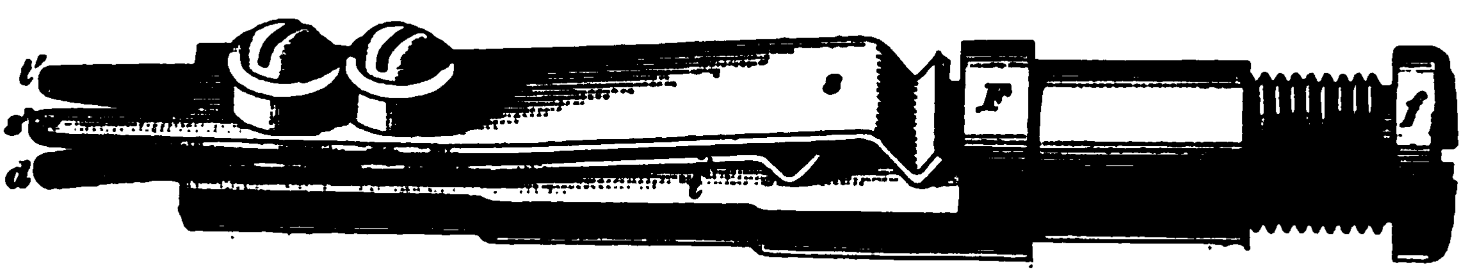


FIG. 13

In this, the framework *F* is secured in position on the panel board by means of a screw-threaded sleeve *f*, as in Fig. 12. The tip and sleeve springs *t* and *s*, respectively, are mounted on the rear portion of the frame by means of two screws passing through the springs and the layers of insulation between them and into the metallic frame. These screws are, of course, insulated from the springs by means of hard-rubber bushings through which they pass. The rear portions of the springs have projecting tongues *s'*, *t'* to which the line connections may be soldered; a similar tongue *d* also projects from the frame *F*, thus forming a terminal for it. The tip spring *t* normally rests on a projection on the frame *F*, in order to complete the connection through the drop, but the insertion of the plug lifts *t* and causes this connection to be broken. One line wire is connected to *t'*, the other to *s'*, and the annunciator between the terminal *d* of the frame *F* and *s'*.

19. Materials and Construction of Jacks.—According to W. A. Taylor, in the Electrical Review, springs for jacks should be of the best spring metal, preferably German silver, punched or cut from the sheet with the grain running lengthwise. Spring German silver containing 18 per cent. nickel is generally used, the length of the spring being sufficient so that it may move twice as far as necessary without receiving a permanent set. The springs should be formed as nearly as possible to the desired shape in the forming press so as to require little or no adjustment by the assembler, as the latter is apt to bend it so much as to render it almost useless. Where it is necessary to use a short spring, the gauge should be thin to permit greater movement without a permanent set. To obtain sufficient tension, the spring may be made wider. The tension of the springs is sufficient if the plugs are held tight enough not to be readily disconnected during the ordinary operation of the switchboard. Excessive tension causes an unnecessarily rapid wear of the plugs and springs.

On magneto-switchboards, contacts between jack springs may be made by bending down the end of one spring, as shown in Fig. 14 (*a*), or the spring may be struck with a punch, which makes the metal protrude on the side where it is to make contact with another spring, as shown in Fig. 14 (*b*); or a contact point may be riveted into one or both springs; in the latter case one rivet is pointed and the other flat, as shown in Fig. 14 (*c*). Where the drop is thrown by means of a magneto-generator, the voltage is great enough to break down a fairly high resistance contact; and as the contact is seldom broken while a current is flowing, no arcing and no consequent corrosion of contacts is produced.

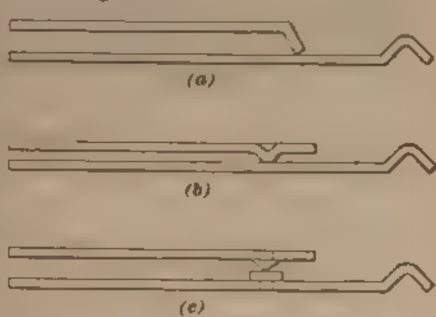


FIG. 14

But where a battery is used to operate a drop or relay, the current usually flows until the circuit is opened by the insertion of a plug in the jack, thus causing an arc, which tends to oxidize the contacts. To maintain continuous service, the material that will best resist oxidization must be used. For this purpose, pure platinum has proved to be the best and cheapest, all things considered. What is true of contacts that carry current from a battery is also true for contacts that carry voice currents. Hence, all contacts in jacks or elsewhere that carry battery or voice currents should be made of platinum rivets in German-silver springs.

For the insulating material in multiple jacks, hard rubber alone should be used, as high insulation is necessary to avoid trouble. Fiber, which is inclined to gather moisture, is bad in central-energy systems, and the black variety, if colored with lamp black, should never be used.

PLUGS

50. Plugs for use on switchboards have been reduced to a standard, so that with good construction all plugs are about the same, varying only in details. There are three kinds: (1) the single-contact plug, (2) the double-contact

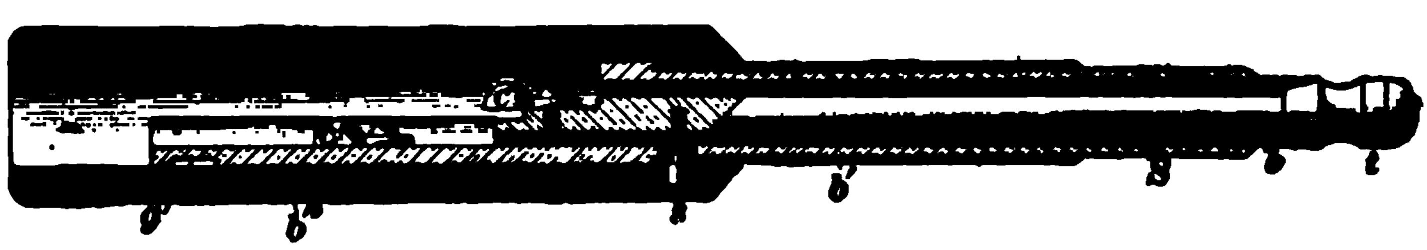


FIG. 15

plug, and (3) the triple-contact plug. The first style is seldom, if ever, used in modern switchboards and will not be described here, as metallic circuits are used in all modern boards. Single-contact plugs were used on the old ground-return boards.

51. Double-Contact Plug.—A double-contact plug is shown in section in Fig. 15. The tip conductor *t* is formed of a brass rod having an enlargement at its forward end. All except the enlarged portion of this rod is encased in a hard-rubber bushing *b*, and over this is slipped a tube *S* of

brass, forming the sleeve conductor. The rear portion of this latter sleeve is covered by a second hard-rubber bushing b', and over this is slipped a heavy bushing b'', which forms the handle of the plug. Carried on the rear portion of the tip conductor t is a conductor c, adapted to form the terminal of one of the cord conductors. A similar connector c' is carried on the rearward extension of the sleeve conductor S and forms the terminal of the other conductor of the cord. These cord terminals c, c' are shown attached to the cord conductors in Fig. 18. The bushing b'' forming the handle is not put in place until after the cord is attached to the terminals c, c', after which it is slid over the plug and the cord, and is secured by the screw s engaging a tapped hole in the tip conductor t. This screw passes

FIG. 16

through, but is insulated from, the sleeve S. The groove g on the rear portion of the sleeve conductor is for the purpose of binding the flexible cord in place by means of a strong linen thread lying within the groove and wrapped tightly around the cord. By this means, the strain due to the weight of the cord and pulley is not exerted at the junction of the conductors and the connectors c, c', but is carried rather by the covering of the cord, owing to its being rigidly bound to the rear portion of the sleeve.

52. The **Clausen switchboard plug**, shown in Fig. 16, has a shell a of insulating material that is held in place by a spring catch b that slips into a small opening in the side of the shell. In this way, the shell can be removed without the use of a screwdriver which is usually required to remove

a screw fastening in most plugs. In removing the shell, all that is necessary is to simply press the spring catch *b* inwards, so as to disengage it from the opening in the shell, which can then be withdrawn. All insulating material in the plug is hard rubber. The interior of the plug is screw-threaded at the cord end to more securely hold the cord in place, and in addition, means are provided by which it is possible to tie the cord to the plug.

53. Triple Contact Plug.—A triple contact plug is shown in Fig. 17. In this style there are three conductors, known as tip *t*, sleeve *s*, and ring *r*. The tip *t* is screwed on to a steel pin that runs back through the hard-rubber insulating sleeve to the connecting block to which the connecting screw is fastened, and in order that the cord conductor may not touch the connecting block *f*, an insulating washer *g*, is placed under the screw and washer *h*. The insulating washer is made large enough so that there will be no stray strands to short-circuit the plug. The sleeve *s* is made from brass tubing and passes through the insulating tube *k* to its

FIG. 17

connecting block *f*, within which it is screwed; the connection is made to the sleeve under the screw and washer *l*. The sleeve connection is made by bending back one of the conductors, when the cord is screwed into the shank of the plug. The strand is thus pinched tightly against the threads, making a good connection. The steel pin in the center, connecting the tip, should be soldered into the connecting block. Then, after the tip is screwed on, this end of the pin should be upset to prevent the tip from becoming unscrewed. If this precaution is not taken, the tip will come off and get lost in a jack and cause trouble.

54. Plugs should be made of brass, as hard as can be conveniently worked, the best grade of hard rubber for

insulation, and red fiber for the handle. Some plugs are made with steel tips and give good satisfaction where they are used enough to keep them bright, but it is rather better to use a metal that will not cut the springs in the jack, for it is preferable to have the plug wear out before the jack. The cutting of jack springs by the plug tip produces a fine metal dust that is apt to cause insulation troubles.

All plugs should be so made that when new they are of uniform length and diameter. They should go into the jack easily and not tight, but should not have any tendency to wiggle. The hole in the shank should be of such size that a standard cord screws tightly into it. The threads should not have sharp edges or the braid and the conductor that is bent back will be cut. Great care must be exercised to have all tools for manufacturing the plug made accurately, and so placed in the screw machine that all parts will be absolutely interchangeable.

55. Cord Connectors in Plug.—The manner of making the connection between the cord and plug is well shown in Figs. 18 and 19, in which *C* is the cord, having two insulated conductors *t'*, *s'*. These conductors are bared at their terminals and clamped between the small lugs projecting from the connectors *c*, *c'*, after which they are securely soldered. The connectors *c*, *c'* are then screwed into place, after which the cord is securely bound to the sleeve tube by means of the linen thread *l*, which is wrapped in the groove, as shown. Before slipping

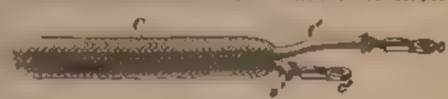


FIG. 18

FIG. 19

on the sleeve *b''* Fig. 15 it is well to give the connectors a coating of shellac, as this tends to prevent any loose ends of the tinsel strands of which the conductors are formed from making short circuits within the plug.

It is not difficult to see that unless a plug is constructed with the greatest care, it will be a source of endless trouble, for the various parts are necessarily placed so very close together that any loose ends or poorly constructed joints are almost sure to form short circuits or open circuits. Especially is this true in the case of some plugs in use with more complicated systems, in which three conductors are used within the flexible cord, thus necessitating three contacts on the plug, all of which must, of course, be insulated from each other.

FLEXIBLE CORDS

56. The **flexible conductors**, by which the temporary connections between the terminals or spring jacks of subscribers' lines are made, are usually termed cords, and as in all other branches of telephony, their construction, in order to give satisfactory service, demands the most careful attention to the minutest detail. The point just back of the handle of the plug is subject to the greatest amount of wear, because it is most frequently handled by the operator, and a sharp bend always occurs, due to the side strain on the cord, when a plug is inserted in a jack.

57. The type of cord shown in Fig. 20 has been found to be very satisfactory, and is available to the independent and also to the Bell companies. In this, the tip and sleeve conductors *t*, *s* are each composed of twisted strands of tinsel, with which a few strands of fine copper wire are intermingled for the purpose of giving greater strength. It has

FIG. 20

been found that a twisted tinsel conductor is better than a braided one, on account of being more flexible. Around each conductor is wrapped a layer of floss silk *a*. It has been found preferable to make the first layer of insulating material a wrapping instead of a braid, because the former tends to bind the strands of the conducting cord more closely

together, thus reducing the liability of the ends breaking off and projecting through the insulating layers to form short circuits. Over the layer of silk is a braiding *c* of cotton rather loosely laid on. After being thus insulated, the two conductors are laid together and served with a wrapping of thread *d*, which binds them into a single cord. A spiral shield of spring brass wire *e* is then slipped over the two conductors, after which a layer of polished cotton is braided tightly over the whole. The spring brass shield serves as a mechanical protection for the cords without impairing their flexibility. Its most important function is to prevent sharp kinks in the cord, which have been found to be very destructive to the conductors within. In order that the end of the cord that receives the most handling and is the most liable

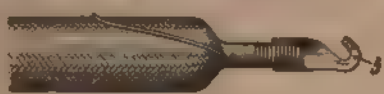


FIG. 21

to be sharply kinked may receive an additional stiffening, the outside layer of cotton is made double for a distance of about 1 foot back of the heel of the plug.

It is important in cords of this kind that the spiral brass-wire shield should be thoroughly anchored at each end, and this is accomplished by wrapping it at each end with strong thread, so that it cannot slide along the conductors. As an addition to this anchoring, the outer braiding of the cord should be made very tight at each end.

58. Kellogg Cord and Plug.—The Kellogg cord is shown in Fig. 21. The center *a* is a strand of twine, *b*, a linen braiding mixed with three tinsel strands; *c*, the inner conductor of spiral steel wire, *d*, a braiding of silk; *e*, a linen braiding; *f*, a loose tinsel braiding; *g*, the outer conductor of

spiral steel wire; *h*, a cotton braid; and *i*, a linen braid. The cord is reenforced at the plug end for a length of 14 inches by another braiding of linen. The tinsel is used to cut down and equalize the resistance of the main steel conductors. At *j* is shown the way in which the tip conductor is finished off at the plug end.

This tip *j* is fastened to the tip conductor of the plug, shown in Fig. 22, by means of the screw *l*. The sleeve

FIG. 22

conductor of the cord is bent back over the linen braid and held firmly in contact with the sleeve conductor of the cord, which has an internal thread at *m*, by the expanding pressure of the braiding, the plug being screwed over the cord and this contact made before the tip conductor is fastened in place.

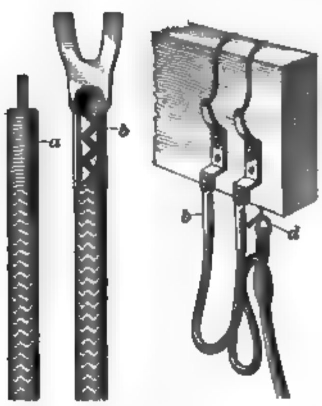


FIG. 23

CORD FASTENINGS

59. The tail-end of the Kellogg cord is finished and fastened to the cord rack in the rear of the switchboard as shown in Fig. 23. At *a* is shown the end of one conductor before the terminal piece *b* is squeezed on. The strain is put on the braiding, rather than on the conductors, by means of a loop that slips over a hook at *d*, which is curled so that the cord cannot bounce off. The conductors are brought out separately from the point where the loop is secured, the sleeve conductor having in its braiding a blue thread to distinguish it from the tip conductor.

60. Split Bushing.—A good method of fastening the stationary ends of switchboard cords is shown in Fig. 24. The cord is clamped by means of a split bushing, shown in detail at the left of this figure. This bushing is composed of two pieces of wood or fiber, which, when laid together, form a conical plug adapted to fit loosely in a hole bored in the rack on which the cords terminate. The cord to be secured is placed between the halves of the bushing, which is then pushed into the hole in the rack, and thus serves to

FIG. 24

clamp the cord tightly without in any way deranging its internal structure. This clamp has proved very convenient in practice, as by it a cord may be clamped in any position desired or entirely removed, almost instantly. The clamp does not injure the cord, which is not the case with many other forms of attachments. Another way to attach a cord to the switchboard is to leave a portion of its external braiding projecting beyond the end of the cord, and to tie the cord in position by this means. This has the disadvantage that it clamps only the end of the cord, and if for any reason it becomes necessary to secure the cord at an intermediate position, some other means must be used.

61. Connections on Terminal Rack.—The connectors to which the stationary terminals of the cords are secured should be fastened rigidly to the cord rack and should present suitable means for attaching the cord conductors without injuring them, and also for attaching the wires with which the cord conductors are to be connected. It is not an easy matter to solder tinsel without burning it, and therefore some manufacturers prefer to clamp the cord terminal between the connector and a washer by means of a screw passing through the two, this method being shown in Fig. 24. Frequently, the wire with which the cord conductor is to connect terminates on the opposite side of the connecting rack from the cord, and in this case such a connector as is shown in Fig. 25 (*a*) is much used. In this connector, the strip *a*, formed integral with the washer portion *b*, is bent at right

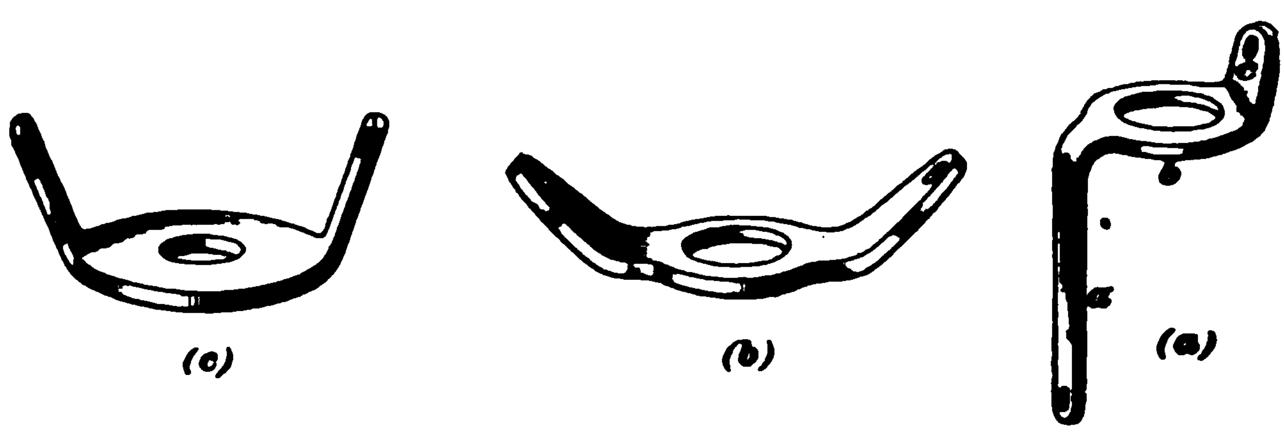


FIG. 25

angles to the body of the connector and projects through a small hole in the board of the terminal rack so as to form a suitable terminal to which the wire on that side of the board may be soldered. The upwardly projecting tongue *c* may or may not be present, according to whether other connections are to be made at this point. The connectors shown in Fig. 25 (*b*) and (*c*) are for use where the wire or wires terminate on the same side of the rack as the cord conductor. When it is desired to solder the cord conductor into place, wire terminals are preferably placed on the ends of the conductors. Such a terminal may be readily made by inserting a piece of No. 22 B. & S. tinned copper wire, about 6 inches long, clear through the cord conductor just back of the end of the braid, as is shown in the left-hand portion of Fig. 26. The two ends of this wire are then

twisted closely around the end of the cord, making a firm metallic connection with the tinsel by binding them closely within the convolutions of the wire. The completed terminal may be made in a minute, with no other tools than the fingers and a pair of pliers, and is shown when finished in the right-hand portion of Fig. 26.

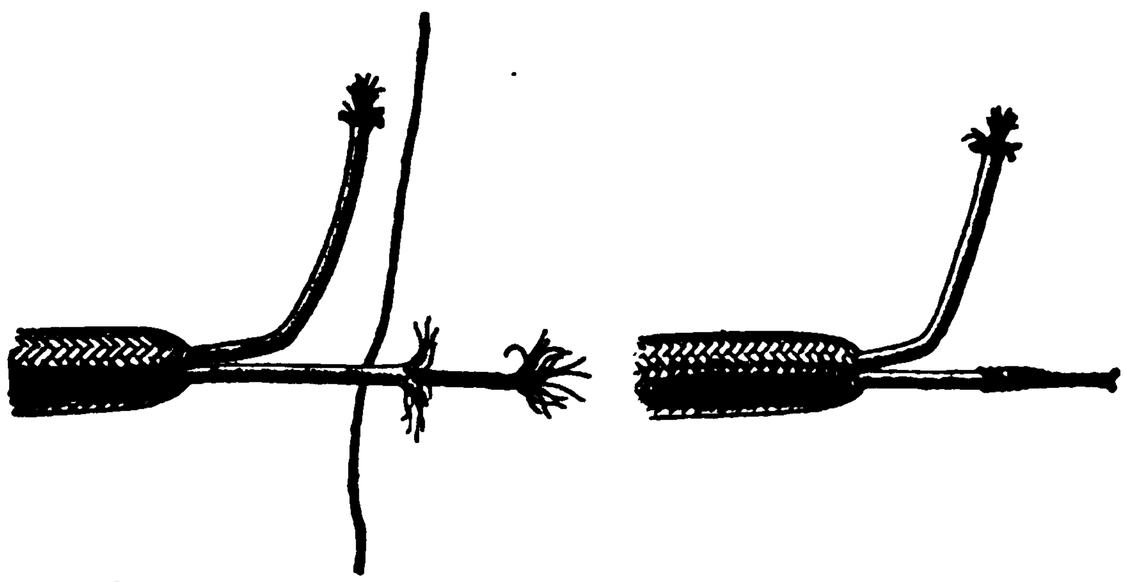


FIG. 26

62. Connectors.—The connectors shown in Fig. 25 are preferably stamped from sheet German silver or from soft sheet copper. They should be polished, usually by tumbling, and be entirely free from oil, which would interfere with the use of solder. Where copper is used, the tips of the connectors should be tinned by being dipped in acid and then in molten tin. In order to prevent the acid from corroding the surface of the metal after a time, they should be dipped, after being tinned, in alcohol, which has been found to almost entirely prevent future corrosion

MAGNETO-SWITCHBOARDS

(PART 2)

MAGNETO-SWITCHBOARD DEVICES

SELF-RESTORING SWITCHBOARD DROPS

1. In the switchboard drops described in *Magneto-Switchboards*, Part 1, it was necessary for the operator to manually restore the shutters, in order to make them ready for another call. This, in an exchange where the operator is kept very busy, is a disadvantage, inasmuch as it increases the number of motions she is required to make in establishing connections between subscribers. One object to be kept in view in the design of switchboards for modern exchanges is to reduce the number of motions necessary on the part of the operator to a minimum, and one of the most important steps in this direction was the introduction of the so-called **self-restoring drop.** The shutter of this drop is restored to its normal position automatically as a secondary result of some other necessary operation, such, for instance, as the insertion of a plug into a jack.

The restoring motion may be imparted to a shutter in two general ways: one, by the action of an electromagnet, the circuit of which is closed by some necessary motion of the operator, such as the insertion of a plug into a jack; and the other, by mechanical means, the plug itself serving to push the shutter into its restored position, either by direct contact or through the intervention of some connecting mechanical link.

ELECTRICALLY RESTORING DROPS

2. Western Electric Drop.—In Fig. 1 is shown the details of an extensively used electrically restoring drop. This is really composed of two tubular magnets *a* and *d*, each of which is secured to a plate *b*. The rear electromagnet *a* is, in reality, a slightly modified Warner tubular drop, having its armature *C* pivoted at *c* in a bracket carried on the rear portion of the tubular shell. The second tubular magnet *d* has its poles projecting toward the front of the board, and is provided with a heavy armature *e* pivoted at its lower edge by the pivot screws e' and e'', which are held

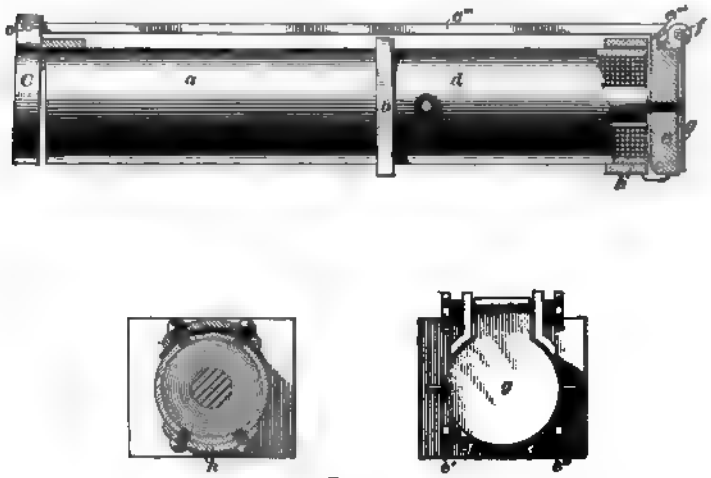


FIG. 1

in a lower bracket *h* secured to the front end of the tubular magnet *d*. The rod c''' secured to the armature *C* is long enough to reach and engage the lug e''' on the upper side of the front armature *e*. Pivoted on the bracket *f*, attached to the upper side of the magnet *d*, is a light aluminum shutter *g* hanging directly in front of the armature *e*. When released by the action of the armature *C* of the electromagnet *a*, the front armature *e* falls forwards by its own weight, pushing the light shutter *g* out of its path. This raises the shutter *g*, so as to display any number or signal behind it, and on the

face of the armature e, to the operator. The connections are so made with the winding of the magnet d that when an operator inserts a plug into the jack of the corresponding line, the circuit through the magnet d will be made complete; and as the circuit includes a battery, the magnet will be energized and the armature e reattracted, thus allowing the shutter g to resume its normal position.

3. Operation of Western Electric Drop.—In order to render the operation of this drop more clear, the circuits leading to both the line magnet a and the restoring magnet d are shown in Fig. 2. In this figure, l represents the line wires leading to a subscriber's station. Connected across these two wires at the central office is the line magnet a of the drop. The springs t and s are connected, respectively, with the two sides of the line wire, and form, in connection with the metallic-contact sleeves or thimbles k and k', the spring jack belonging to that line. The tip and sleeve contacts of the plug are represented by t' and s', and a third contact s'', merely a brass collar or sleeve, is provided on the plug for making an electrical connection between the two thimbles k, k' of the jack when the plug is inserted. The thimble k is grounded through a battery B, and one terminal of the electromagnet d of the drop is connected with the thimble k', while its other terminal is grounded. When a current from the subscriber's station comes over the two wires of the metallic circuit l, the electromagnet a is energized, and by attracting its armature C releases the forward armature e and allows it to push the shutter g out of its normal position

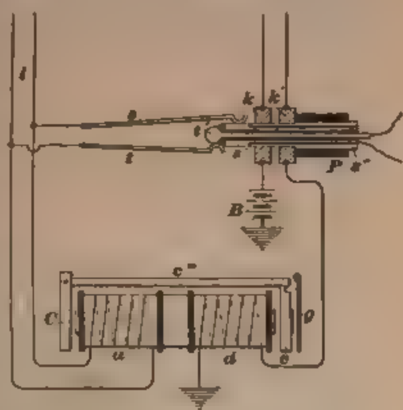


FIG. 2

When an operator inserts the plug P for the purpose of answering this call, the tip and sleeve contacts t', s' on the plug make contact, respectively, with the tip and sleeve springs t, s of the jack, and thus connect the cord circuit across two sides of the line circuit. At the same time, the second sleeve s'' on the plug short-circuits the two thimbles k, k', thus completing the circuit through the electromagnet d and battery B, this circuit being traced from the positive pole of the battery through thimble k–sleeve s''–thimble k'–winding of magnet d–ground–negative pole of battery. The energizing of this magnet causes the attraction of the forward armature e, and allows the shutter g to fall into its normal position. It is thus seen that the restoring of the shutter is performed without any additional effort on the part of the operator.

MECHANICALLY RESTORING DROPS

4. American Electric Telephone Company's Drop and Jack.—The **American Electric Telephone Company's drop and jack** is shown in Figs. 3 and 4, and the plug, which is of special construction, in Fig. 5. In Fig. 3,

FIG. 3

the entire mechanism of one drop and jack is shown in perspective, while Fig. 4 is a plan view of the mechanism with the drop magnet removed.

The drop magnet is mounted directly above the jack, and the shutter is so arranged that when released by the armature, a projection on it falls in front of the jack-opening.

The plug carries a collar, which, during the insertion or withdrawal of the plug from the jack, engages this projection on the shutter and serves to mechanically raise the shutter to its normal position. The back panel of the switchboard is shown at *f*, Fig. 3, and is provided with two holes for each jack, through which the machine screws *l*, *l'* pass when

FIG. 4

the combined drop and jack is in place. These two screws *l*, *l'* serve not only to hold the drops and jacks in place, but also as a means for connecting the line terminals with the various circuits of the mechanism. The back panel *f* is also provided with strips *h*, *h* and *h'*, *h'* with which the springs *g*, *g* and *g'*, *g'*, secured to the back of the drop, engage when the drop is clamped in position. The two lower strips *h'*, *h'* form the terminals of the switchboard generator, and the springs *g'*, *g'* are connected, respectively, with the long spring *j* and the spring *i* on the opposite side of the jack, so

FIG. 5

that these two springs *j*, *i* form terminals of the switchboard-generator circuit. The line springs *t*, *s* are arranged between the generator springs and are adapted to make contact with the tip and sleeve conductors *t'*, *s'*, respectively, of the plug, when inserted into the jack. The line spring *s* is connected directly with the terminal screw *l*, while the line spring *t* is connected through the coil *a* of the drop with the other terminal screw *l'*.

5. The drop is composed of the electromagnet *a*, which is enclosed in a sheet-iron box *b* that forms a partial magnetic shield for the prevention of cross-talk. The armature *c* is pivoted, as shown at c', at the rear portion of this shield and has a forwardly projecting lever c'', holding the shutter *d* in position in the ordinary manner. The projection d' on the face of the shutter falls in front of the jack-opening when the shutter is down. When the plug is inserted in the jack, the collar *k* on the plug engages the projection d' and forces the shutter into its raised position. If, while the plug is in, the drop is again actuated as a clearing-out signal, the projection d' falls in front of the collar *k*. By this means, when the plug is withdrawn from the jack, the collar *k* will again be pressed against the projection d', again restoring the shutter.

6. It has been said that the terminals of the switchboard-generator circuit were brought into proximity with each jack by means of the springs *j* and *i*, one, *j*, occupying a position opposite the tip spring *t* of the jack, and the other, *i*, a similar position on the other side of the jack-tube. In order to call a subscriber, therefore, the operator has only to press the plug into the jack as far as it will go. This causes the collar *k* to slide back on the plug against the pressure of the spring within the plug handle. The tip spring parts contact with the tip of the plug t', and rides on the enlarged portion *m*, thus forcing spring *u*, lying parallel to the tip spring, into engagement with its generator spring *j*. This connects one terminal of the generator to the line screw l' through the spring *j*, spring *u*, and metallic strip *v*. The sleeve spring is at the same time electrically connected with the generator spring *i*, because the sleeve s' on the plug touches both the sleeve spring *s* and the tip spring *i*. Thus the two sides of the line are connected with the terminals of the switchboard generator.

The two strips *r*, *r* projecting from the front of each jack form the terminals of the night-alarm circuit, the connection to them being completed by means of the springs *g*, *g* and

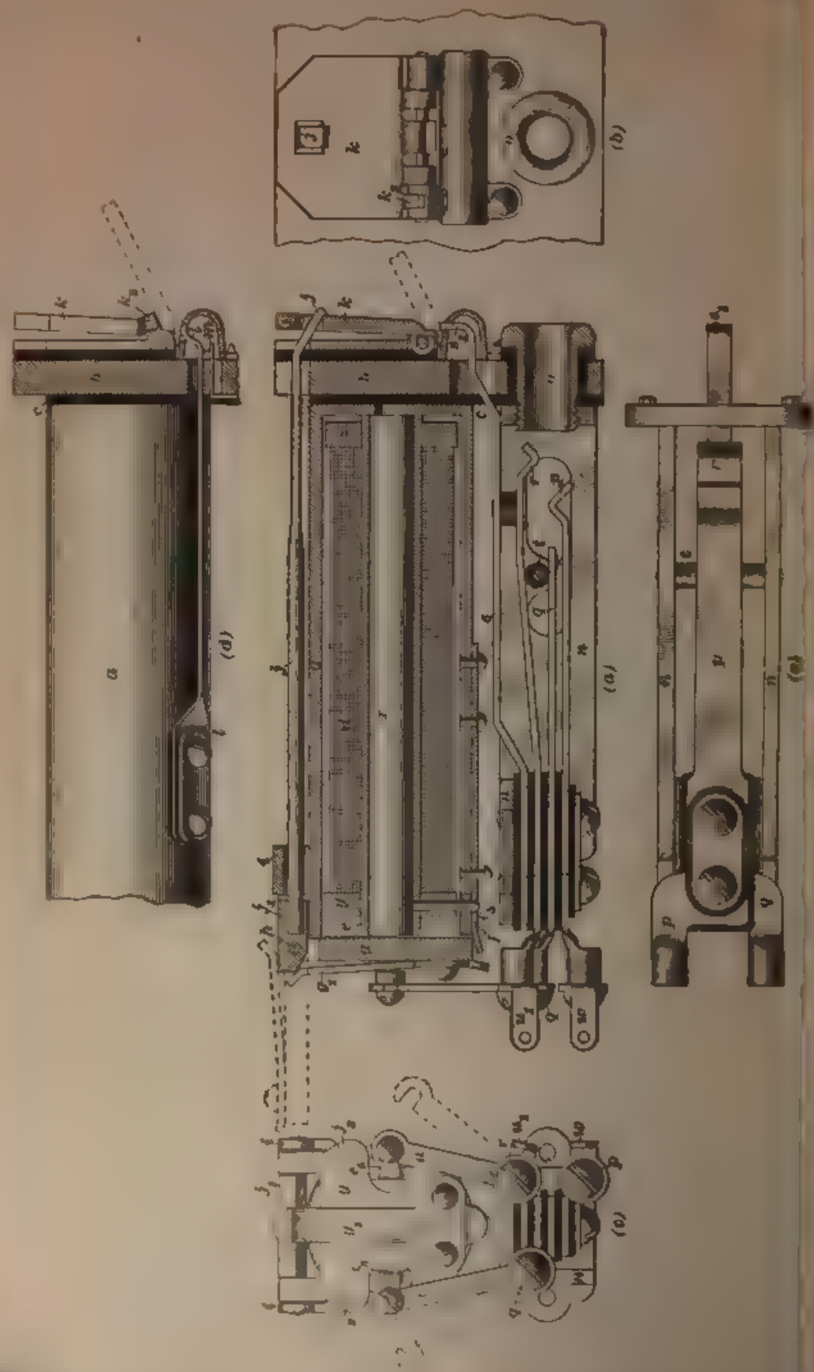
the strips h, h, already referred to. When the shutter falls, it bridges across the two wires r, r, thus completing the circuit and sounding the bell.

7. **Tubular Bell-Express Drop and Jack.**—The American Electric Telephone Company makes another form of combined restoring drop and jack, shown in Fig. 6, which it calls its **self-restoring tubular Bell-express drop and jack.** The term Bell-express is probably applied because the drop is used on the so-called Bell-express type of switchboards, the term Bell-express implying a switchboard resembling similar switchboards used by the Bell companies and operated with the speed of an express train, that is, very rapidly compared with a manual-restoring drop

FIG. 6

board. This drop and jack is self-contained and may be easily removed as one part by loosening two screws a, b that secure it to the iron strip c. Substantial terminals are mounted in the rear fiber end piece and a soft-iron shell encloses the coil. The armature d and shutter arm e are copper-plated. The German-silver jack-springs are bolted to the shell of the drop, mica insulation i being inserted between the springs. When the plug is inserted in the jack, the movement of the spring f restores the shutter to its normal position. The connections between the coil and jack-springs are soldered and the night-alarm contact is of a wiping nature.

8. **The Dean Electric Company's Drop and Jack.** All the principal working parts of this piece of apparatus are



shown in Fig. 7, (*a*) being a cross-section and (*b*) and (*c*) front and rear views, respectively. The drop is of the tubular type, having a one-piece drawn-steel outer shell *a* that is attached to a front, or mounting, plate *b* by means of two screws passing through hard-rubber bushings. An intervening sheet of hard rubber *c* is provided to complete the insulation of the drop from all other parts of the combination. The actuating coil *d* is enclosed within this shell, but instead of being wound directly on the solid core, as is usually the case, it has a soften-iron tubular portion *e* on which the fiber heads *y*, *z* are driven to form a spool. The Norway-iron core *x*, over which this tubular-cored spool easily slides, is riveted securely into the head of the drop shell, thereby substantially forming a one-piece magnetic circuit. The tubular core of this spool is made about $\frac{1}{64}$ inch shorter than the inner core, so that when the spool is slipped into place and locked by a spring catch *f* that engages the pin *e*, located in the spool head, its end will clear the armature *g* regardless of any slight inequalities in the manufacture of the spool, or inability to force it completely into the shell. The coil of this drop is thus made interchangeable and can be removed and replaced without any possibility of changing the air-gap between the armature and the core.

In order to facilitate the removal of the coil, a special armature construction is employed. An annealed Norway-iron armature *g* is pivoted by the pin *h* to the bracket *i*, which is securely fastened to the drop shell. The shutter hook *j* has an enlarged portion j_1, which is also pivoted on the pin *h*. A flat spring g_1, fastened to the lower portion of the armature *g*, is made to engage the enlarged portion of the shutter hook j_1 and normally hold the two firmly together, so that when the core attracts the armature the hook *j* will release the shutter *k*. This spring g_1 acts similar to that in a jack-knife by allowing the armature to swing up and be held out of the way, as shown in Fig. 8, and permit the spool to be withdrawn from the drop shell. The portion j_1 of the shutter hook has two downwardly projecting wings j_2, j_3, Figs. 7 (*c*) and 8, which serve as limiting stops for the armature when it is in its

normal position. The drop spools can thus be readily taken out and replaced without disturbing the armature mechanism and without danger of losing any small parts or damaging the adjustment.

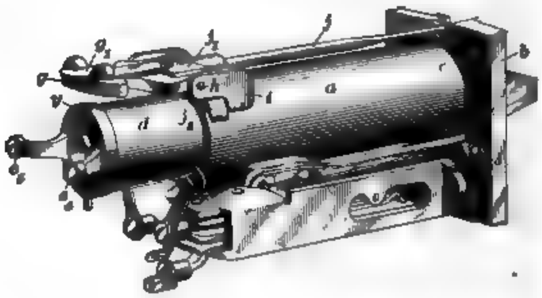


FIG. 8

The drop shutter *k* is of the usual gravity type, but is provided with an opening near the top through which the hook passes when the shutter is in its up-position. The end of this hook has a downward bend, so that should the armature become stuck and the hook consequently kept raised, the shutter, as it is restored, will strike the same and force the armature beyond the distance through which the residual magnetism of the core will act. This is a very important feature in the construction of sensitive working drops that are designed for very small operating currents, as these drops are also subject to heavy ringing currents, which tend to make the armature "stick."

9. In Fig. 7 (*d*) is shown the night-alarm contact of this drop. It consists of a long, flexible, German-silver spring *l* mounted on the outside of the drop shell and normally insulated from it and the remainder of the drop. The end of this spring extends through an opening in the mounting plate and is so shaped as to be forced down by the projection k_1 on the shutter when the latter falls. This causes a platinum surface on the spring *l* to make a pressure contact with the platinum rivet in the other spring *m* and thereby complete the night-alarm circuit. The platinum points and gravity pressure employed in this night-alarm mechanism

insures a safe low-resistance contact that will allow a low-voltage battery and bell to be utilized.

10. The spring jack of this combination is made with a rigid sheet-steel frame *n*, as shown in the sectional view, Fig. 7 (*a*), and in the bottom view of the jack, Fig. 7 (*c*). The threaded metal thimble *o* passes through a rubber-bushed hole in the mounting strip and screws into the jack-frame *n*, holding the latter securely in place. This thimble serves as the sleeve of the jack through which the plug is inserted. The jack-springs *p*, *q*, *r* and shutter-restoring spring *s* are insulated from each other by hard rubber and are attached to the drop frame by two screws. When the plug is inserted, the sleeve spring *r* is raised, which in turn causes the restoring spring *s* to lift its projecting end s_1 and force the drop shutter *k* into its restored or up-position. On withdrawing the plug, the springs *r* and *s* return to their normal position against the insulated stop *t* and the shutter is retained by the hook *j*.

The plug on being inserted also engages the tip spring *p* and causes it to open contact with the local spring *q*, the latter being connected to the drop winding as subsequently described. These springs normally rest on the insulated stop *t* whose function is to keep all the jack-springs normally lined up with respect to the opening in sleeve *o* when they are under initial tension.

The terminals c_1 and c_2 of the drop winding are located in the spool head *y* so as to project through two openings in the armature, as shown in Fig. 7 (*c*). Two connecting links *u*, *v* from the sleeve jack-spring *r* and local contact spring *q*, respectively, extend upwards and hook under the terminal screws c_1 and c_2. These links carry the drop circuit to the line terminals *u*, and *w*, the former direct and the latter through platinum contacts on the local spring *q*, to the tip spring *p*, and thence to the line through the terminal *x*. The drop winding is thus cut off from the line circuit when the plug is inserted in the jack.

GENERATOR-CALL VISUAL SIGNALS

11. Where generators are used by subscribers to call up the exchange and the rapidity of operation of a common-battery signaling system is desired, **generator-call visual signals** are used. These signals, after being operated by the generator current, are locked in their operated position by current from a battery. A line signal is usually restored by gravity when the operator opens the battery circuit by the insertion of a plug in the line jack; a clearing-out signal is usually restored by gravity when the operator removes the plug from the jack, or closes the listening key to determine if both subscribers are through with their lines.

12. Mason Generator-Call Target.—The generator-call visual signal and jack made by The Sumter Telephone Manufacturing Company is shown in Fig. 9 (*a*). Mr. Mason, the inventor, says that experience shows that a jack seldom requires repair or adjustment after it is installed, whereas the signal is liable to injury or disarrangement due to lightning or other causes; hence, he has arranged this signal and jack so that the signal can be easily removed or inserted without disturbing any other part of the switchboard and without requiring any soldered joints. The jacks are assembled in horizontal strips, the space between adjacent strips being just wide enough to receive the signals.

Each signal, which is located immediately below a jack, consists of a rectangular frame of metal, the front wall of which is provided with a slot that permits a shutter, or target, *n* to fall into view when the iron core attracts and thus raises the iron armature *j*, which is arranged to rotate about two horizontal pivots *g*. When the core loses its magnetism, the weight of the armature *j* is sufficient to raise the target *n*, which can be made of thin and light material.

Secured between strips of insulation mounted on the rear of the rectangular frame of the drop are two springs *l*, *p* having projecting clips at their rear ends, to which are soldered the terminals of the coil *k*. The front ends of the

springs *l*, *p* are provided with an upward bend that brings them into engagement with contacts *d*, *q*, respectively, projecting laterally from the jack-springs *c*, *r*, so that, as the signal is shoved into position, the proper circuit connections are made between it and the jack above. Fig. 9 (*c*) is a view looking up at the under side of the jack. A third spring *m*, secured between insulating strips at the rear, is so bent and

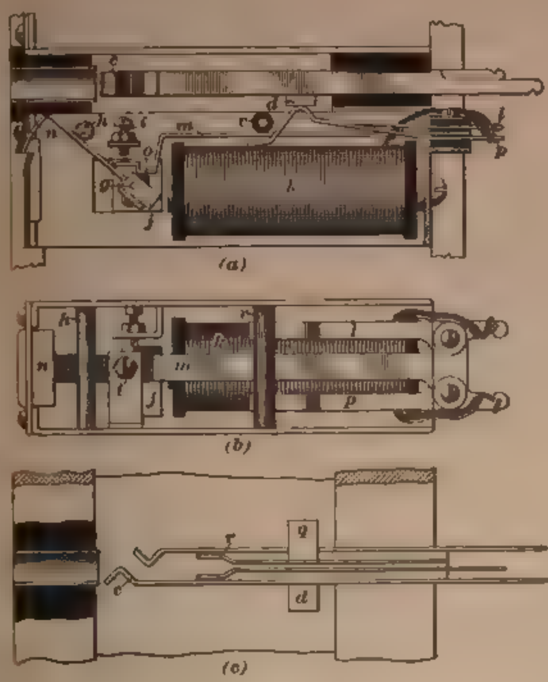


FIG. 9

arranged that when the drop attracts its armature, a projection *o* on the armature raises *m* into contact with an adjustable screw *t*. The cross-rod *h* limits the upward movement of the target and the cross-rod *i* gives the spring *m* its necessary downward trend. On the rear of each signal, there is a lug through which a screw passes to securely hold the signal in position.

13. The coil may have one or two windings and may be connected as shown in either Fig. 10 (*a*) or Fig. 10 (*b*), in which the parts are lettered the same as in the preceding figure. In Fig. 10 (*a*) the current from a subscriber's generator will flow through the path *x–c–d–l–k–p–q–r–b–y*, thereby attracting the armature, which causes the target to fall into view and the contact at *i* to be closed, thus allowing current from the battery *B* to flow through *i–m–z–k–l–d–c–e* back to *B*. Consequently, when the current from the subscriber's station ceases, the battery current will continue to hold the target in view until the operator inserts a plug in the jack

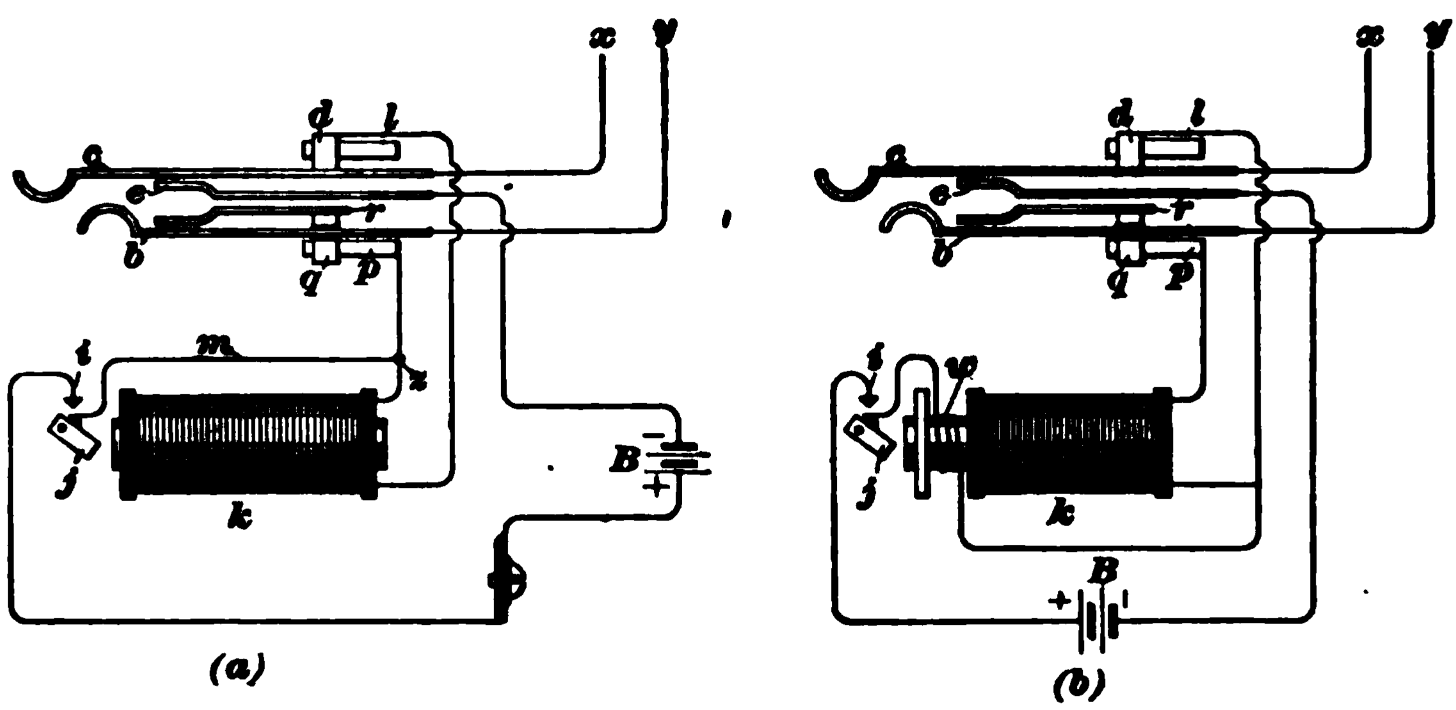


Fig. 10

associated with this signal, which operation separates the spring *c* from *e* and *b* from *r*, thus opening the battery circuit at *e* and connecting the line springs *b*, *c* to the plug contacts. The target now returns to its normal position and opens the battery circuit at another point *i*, so that when the plug is withdrawn the target still remains hid from the operator, although the battery circuit is now closed between the jack-springs *c*, *e*.

Fig. 10 (*b*) operates in exactly the same manner, except that a separate winding *w* is provided for the local battery circuit, which is the more convenient arrangement in many cases.

14. Stromberg-Carlson Signal.—The generator-call visual signal made by the Stromberg-Carlson Telephone

Manufacturing Company is shown in Fig. 11. The coil and moving parts are almost enclosed by the iron frame *u v u* and the front piece *f*, on which appears the line number and a glass window *g*. The bar *d* is used to hold the frame together, while the coil is held in the frame by a nut and screw *h* and by screws that pass through each side of the frame into the fiber head *i*. When a subscriber turns his generator, a current is sent through the high-resistance line coil *m*, thereby causing the core to attract the iron armature *a*, which is pivoted on horizontal pivots at *e*; the armature moves

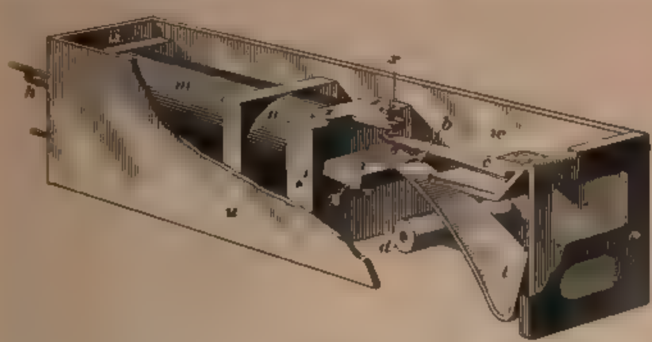


FIG. 11

downwards and the aluminum target *t* rises and shows its signal, a bright surface, through the window *g*. At the same time, the piece *b* lifts the contact spring *c* against the adjustable screw *x*, thereby closing a local circuit that allows current from a common local battery to flow through the small locking coil *n*, thus magnetizing the core sufficiently to hold the target exposed until the operator inserts a plug in the jack associated with this signal, which cuts off the battery current, releases the armature, and drops the target to its normal position, out of sight of the operator.

15. When the subscriber rings off, the clearing-out signal, which is like the line signal, is operated in the same manner and is restored by gravity when the operator opens the local circuit by throwing the listening key into the listening position to ascertain if either subscriber desires another

connection. Current for the locking coil *n* of these signals is furnished by dry cells in very small exchanges and by Gordon cells in larger systems. The locking coil has no connection with the line or ground. In case a call not intended for the operator is sent over a party line, the target may be restored by pressing a non-locking key mounted at the right of the operator's position in the front of the switchboard just below the edge of the key shelf.

In the normal position of the signal, there should be a slight space between the contact spring *c* and the spring *b*, also between *c* and the adjustable screw *x*. The line coil may be obtained wound to a resistance of 250, 500, or 1,000 ohms. The makers claim that an operator can handle 200 lines equipped with these signals almost as easily as 100 lines equipped with mechanically hand-restored drops.

LISTENING AND RINGING DEVICES

16. In establishing a connection between two subscribers, several switching operations have to be performed by the operator in connecting her telephone with the circuit of the calling subscriber, and later across the circuit of both subscribers, and also in ringing either one or the other of the subscribers, as conditions may require. To accomplish these changes, many forms of switching mechanisms have been devised. At one time, very elaborate keys were constructed, the springs of which could be placed in any one of four positions by one hand. In the normal position, the answering and calling plugs were connected together; in the second position, the listening set was connected across the cord circuit; in the third position, the ringing generator was connected across the calling plug; and in the fourth position, across the answering plug. Such keys seem to have gone out of use and a nearly standard form of listening and ringing key like that shown in Fig. 12 is now more generally used.

17. Dean Keys.—In Fig. 12 is shown the Dean Electric Company's ringing-and-listening key *L* and ring-back

key R fastened on one escutcheon plate s, which permits of mounting the whole device directly on the wood of the key shelf. Key L is self-locking in the listening position, that is, with the handle to the right. Both L and R automatically restore from the ringing position, that is, with the handles toward the left, when released. The ring-back key R enables the operator to ring the bell of the original calling

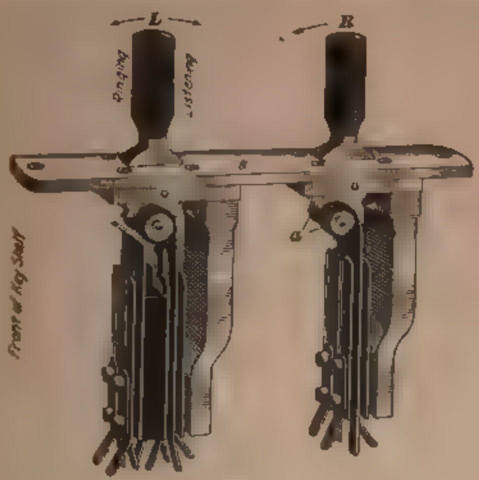


FIG. 12

subscriber should he have hung up his receiver before the party called for is obtained.

The framework of these keys is made very rigid from heavy brass stock. The cams are in one piece, with stops to limit their movements, while the cam-handles are attached by large steel screws that are sufficiently long to reenforce the parts and prevent breakage. The rollers a for reducing the friction of the cams on the springs are securely fastened to prevent them from working loose. The springs are German silver, with riveted platinum contacts, while all the insulation is hard rubber. These keys have an easy and positive action, with no sliding friction, thus insuring long life.

SWITCHBOARD CIRCUITS

18. Connection of Keys.—The connections of a cord circuit containing ringing and listening keys are shown in Fig. 13. In the normal position of the key handles *R*, *L*, the tip of the answering and calling plugs are connected together, as are also their sleeves. When *L* is pushed away from the operator, to the right in this figure, the springs *a*, *b* touch contacts *1*, *2*, respectively, and the operator's listening set is connected through *1–a–7–e* and *2–b–8–f* across the answering plug and through *1–a–3–c* and *2–b–4–d* across the calling plug. When *L* is drawn toward the operator, to the left in this figure, the ringing generator is connected through *m–5–c*

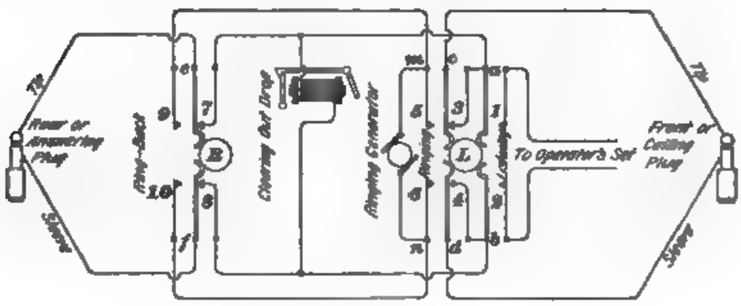


FIG. 13

and *n–6–d* across the calling plug, while the circuit across the answering plug is opened at contacts *3*, *4*. When *R* is drawn toward the operator, to the left in this figure, the ringing generator is connected through *m–9–e* and *n–10–f* across the answering plug, while the circuit to the calling plug is opened at *7*, *8*. When ringing the called-for subscriber, no ringing current flows through the waiting subscriber's receiver and annoys him; similarly, if it is necessary to ring back for the calling subscriber, on account of his having hung up his receiver before the called-for subscriber answers, the ringing current does not flow through the called-for subscriber's receiver and thus annoy him.

19. In Fig. 14 is shown practically the same cord-circuit connections as actually installed in a Kellogg-express type

of switchboard. A color scheme is followed in the insulation of the wires that are grouped in cables, so that circuits may

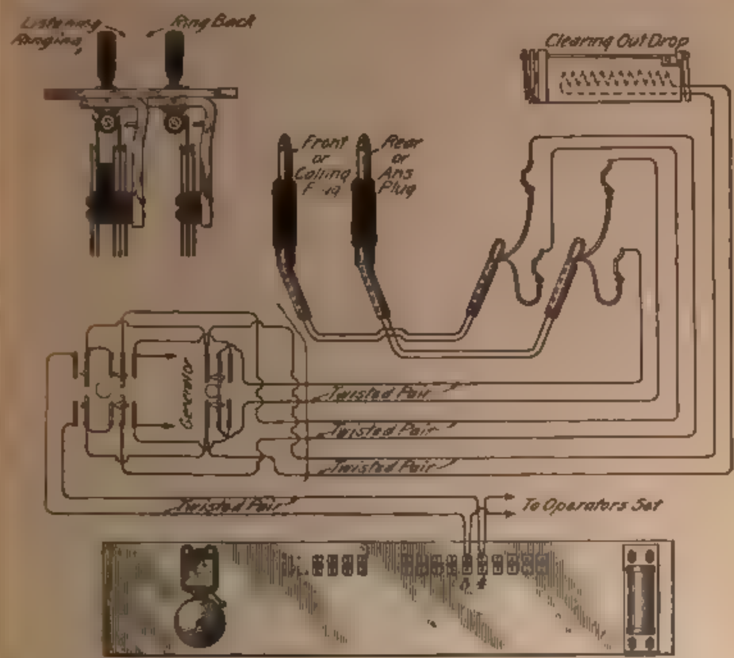


FIG. 14

be traced through without the necessity of testing. A pair of Kellogg keys is also shown in this figure.

20. Operator's Circuit. In Fig. 15 is shown the connections of the **operator's circuit**, as actually installed. Each and every talking circuit is wired as a twisted pair throughout its length, thus eliminating all cross-talk due to induction in the switchboard wiring. Thus, the wiring of the transmitter circuit from lug 8 is led considerably out of the way and looped back so that the circuit may be wired as a twisted pair. Three gravity cells are used to supply current to the transmitter.

At *A* is shown a cut-in jack. Each operator is provided with a head-receiver connected by a flexible cord to a cut-in

plug C, which is used by her alone. When she starts work, she inserts her cut-in plug in the cut-in jack, thereby connecting her receiver to the strap wires running to all listening keys at her position and also closing the transmitter-battery circuit.

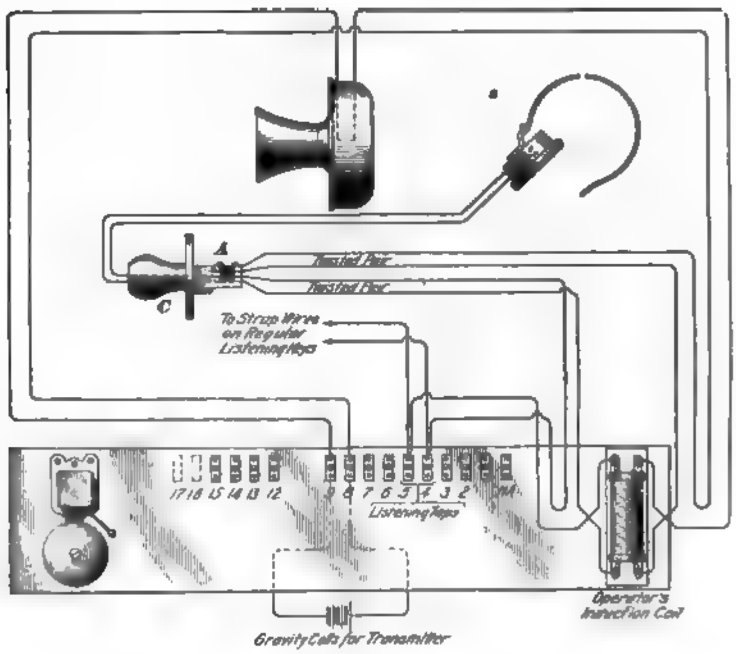


Fig. 15

21. Night-Alarm Circuit.—In Fig. 16 is shown the **night-alarm circuit** used on Kellogg-express switchboards. In order that there shall be no failure in the operation of the night alarm due to poor or dirty contacts at the line-drop shutters, these contacts are used merely to close a circuit containing fifteen dry cells, giving about 20 volts, and a sensitive 500-ohm night-alarm relay, the construction of which is sufficiently well shown in this figure. The magnetic circuit consists of a core, the L-shaped iron piece c that is rigidly secured in position with one end against the iron core, and the L-shaped armature a that is pivoted on the edge of c; the

spring *e* tends to keep the lower end away from the core. When the end *a* of the armature is attracted by the core, the other end lifts sufficiently to bring the spring *e* in contact with *n*, thereby closing another local circuit containing an ordinary bell and two dry cells. The relay springs are provided with platinum contacts and the whole relay is enclosed in a drawn-steel shell to protect it from dust. The relay will operate through 1,000 ohms on 20 volts; hence, the contact resistance at the drop is never apt to interfere with the

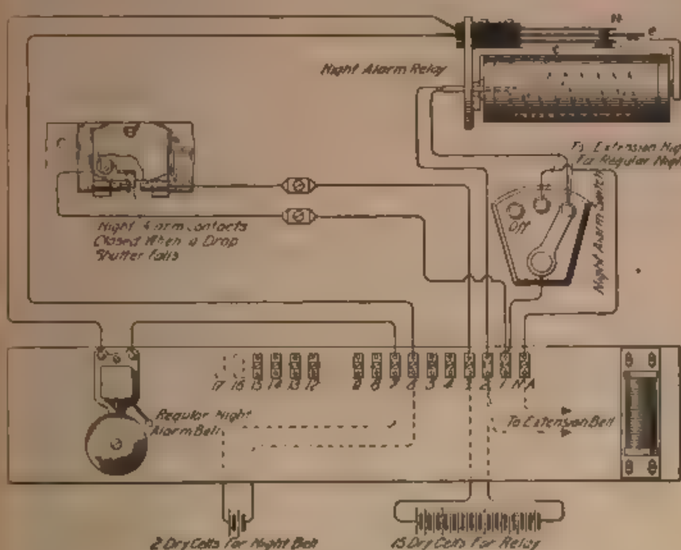


FIG. 16

operation of the relay. The steel shell does not interfere with the magnetic action of the relay because the iron core, piece *c*, and armature *a* form a good magnetic circuit.

By placing the arm of the night-alarm switch on the middle contact, an extension battery bell, placed in any other room in the building, is connected in series with the fifteen dry cells and controlled by the contacts on the drops, the night-alarm relay with the regular night-alarm bell being cut out.

The connections of the bars, or terminals, not shown in Fig. 14, 15, or 16, are as follows: *12* is connected to the grounded terminal of the power alternating-current ringing generator, also to the hand generator and to one strap wire of all ringing keys at that operator's position; *13* is connected through a 110-volt 16-candlepower lamp to the other terminal of the power generator, also to the switch that controls the use of either the power or hand generator; one of the other two contacts of the latter switch is connected to the other terminal of the hand generator and the other contact to the other strap wire of all ringing keys at that operator's position; *14* and *15* are connected through 110-volt 16-candlepower lamps to sources of negative and positive pulsating currents, respectively, and also to the selective-ringing keys used with selective-ringing, pulsating-current party-line systems. When furnished, bars *16* and *17* are used in connection with transfer lamp-signal circuits.

22. Repeating Coil in Cord Circuit.—It is frequently desirable, especially on toll switchboards, to arrange a repeating coil so that it may be cut in or out of a cord circuit connecting two line circuits, by means of a simple switchboard key. Such an arrangement is shown in Fig. 17.

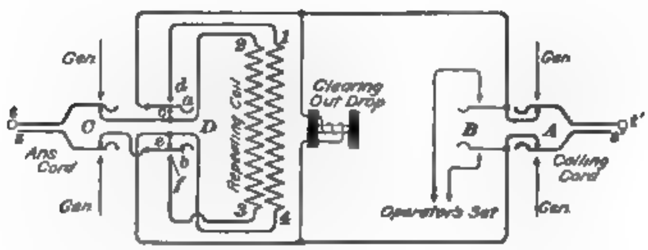


FIG. 17

When the springs *a*, *b* of the key rest in their normal position against contacts *c*, *e*, respectively, the tips *t*, *t'* and sleeves *s*, *s'* of the plugs are connected directly together; but when the key is operated, *t'* is connected through *d* to *1*, *s'* to *4*, *t* to *2* and *s* through *f* to *3*. Thus one winding of the repeating coil

is connected across each side of the circuit, consequently the two sides of the circuit are connected only inductively through the repeating coil. *A* is the regular ringing key, *B* the listening key, and *C* the ring-back key.

BELL-EXPRESS TYPE OF SWITCHBOARD CIRCUIT

23. In Fig. 18 is shown a **Bell-express type of switchboard** as wired by the American Electric Telephone Company. The use of the mechanically restoring line drop and the tubular clearing-out, or ring-off, drop made by the same company and already described is shown in this figure. The construction of this company's ringing and listening keys, which have German-silver springs of proper length and provided with platinum contact points, is shown at *R* and *L*, the connections being shown immediately below the keys. The movement of the springs is effected by an insulated roller mounted on the handle, thus putting the friction and wear on the roller and not on the springs.

When the handle *L* is pushed away from the operator (to the left), her listening set is connected across the answering and calling plug; when pulled toward her (to the right), the ringing wires *b*, *d* are connected across the calling cord only; and when the ring-back key *R* is pulled toward her (to the right), the ringing wires are connected across the answering plug only.

24. Master Selective-Ringing Key.—The ringing wires from all keys in one operator's position are collected together at some point *l*, from which point a single pair of wires lead to the selective-ringing key that is used for selecting the desired telephone when the Leich selective-ringing, four-party-line telephones are used. When only one such key is thus used at each operator's position on a switchboard, it is called a **master selective-ringing key**.

When the key *A* is pressed, ordinary alternating current, having a frequency of about 20 cycles per second, is supplied to the ringing wires from either a hand generator *H G* or a

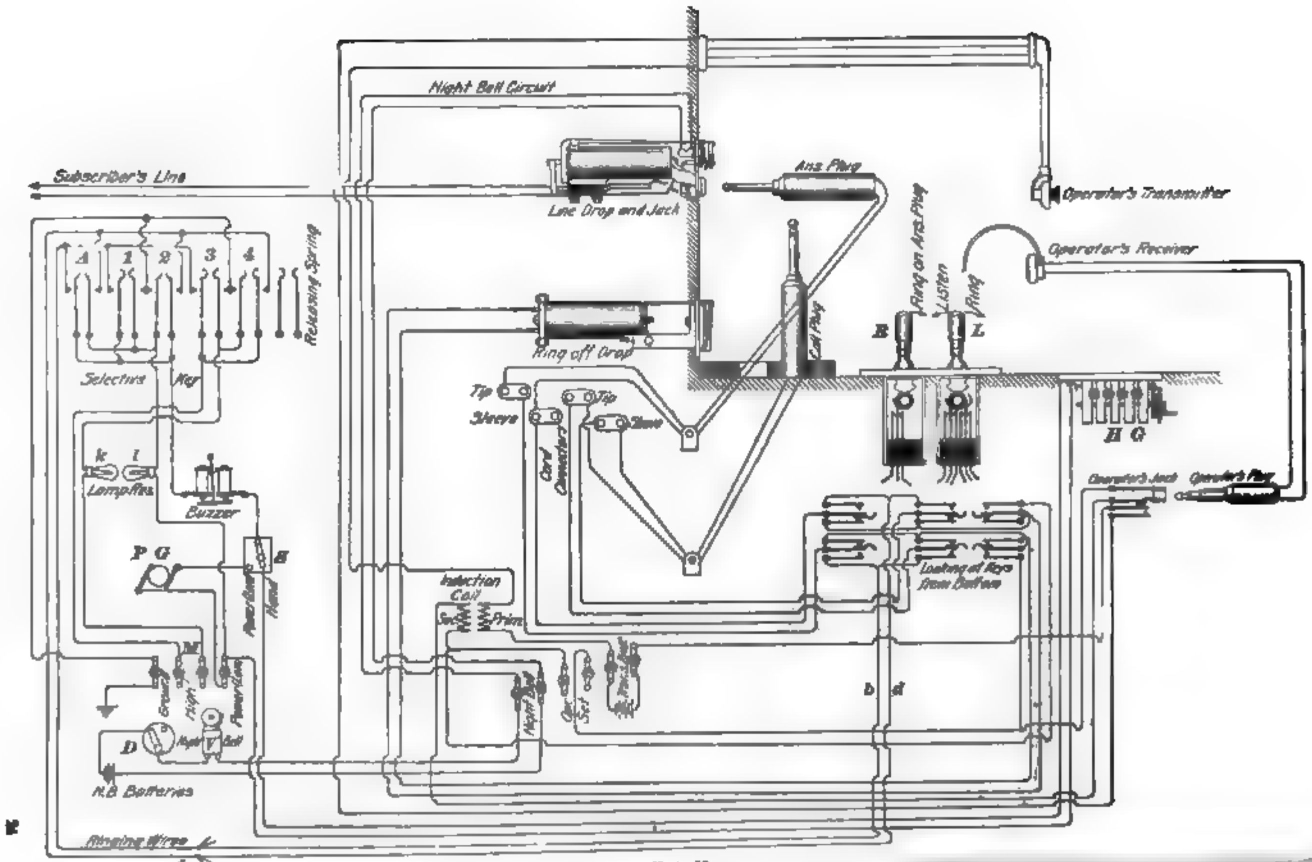

Night Bell Circuit
Subscriber's Line
Line Drop and Jack
Ans. Plug
Operator's Transmitter
Operator's Receiver
Ring on Ans. Plug
Listen
Ring
B
L
Call Plug
Ring off Drop
A
1
2
3
4
Releasing Spring
Selecting Key
Tip
Sleeve
Cord Connectors
H G
Operator's Jack
Operator's Plug
k
l
Lamp Res.
Buzzer
P G
Looking at Keys from Bottom
Induction Coil
Sec.
Prim.
Ground
High
Power Line
Night Bell
Set
b
d
D
H.B. Batteries
Ringing Wires

Fig. 18

power generator *P G*, depending on the position of the switch *S*. The hand generator is used on very small boards or on larger boards during the night or such other times as the power generator cannot be run. The key *A* enables the operator to ring an ordinary telephone when it is the only one connected across a line circuit. Such a telephone is frequently called a private-line telephone to distinguish it from a party-line telephone.

When the key *1* is pressed, the low-frequency generator is connected between the tip conductor and the ground; when *2* is pressed the low-frequency generator is connected between the sleeve conductor and the ground; when *3* is pressed, a high-frequency generator, giving 60 cycles per second, is connected between the tip conductor and the ground; when *4* is pressed the high-frequency generator is connected between the sleeve conductor and the ground.

Any selective key will remain depressed until another selective key is pressed. Pressing the button of the releasing spring mechanically restores any key that may be depressed. To ring with this key, the operator first presses the proper selective key, then closes the regular ringing key associated with the cord circuit she is using. The Leich party-line telephone system will be fully explained elsewhere.

25. *V* is the night bell; it may have its circuit opened or closed at the switch *D*. The buzzer is used on small boards to inform the operator whether ringing current is being properly sent through the line. The lamps *k*, *l*, one in high- and the other in low-frequency generator circuits are used merely as non-inductive resistances to prevent damage to the ringing generators in case there should be a short-circuit, caused by a cross, or otherwise, on any line. This figure is a good example of the way in which switchboard circuits are sometimes drawn.

MISCELLANEOUS DEVICES

26. Cutting Out Operator's Transmitter.—When an operator is listening on a line, it is sometimes very desirable to arrange her set so that she may prevent the noises made in the central offices from being heard by the subscriber while talking to her. There are several methods for accomplishing this result. One method is to connect a push button in series with the primary winding of the operator's induction coil, as shown in Fig. 19. The push button, in its

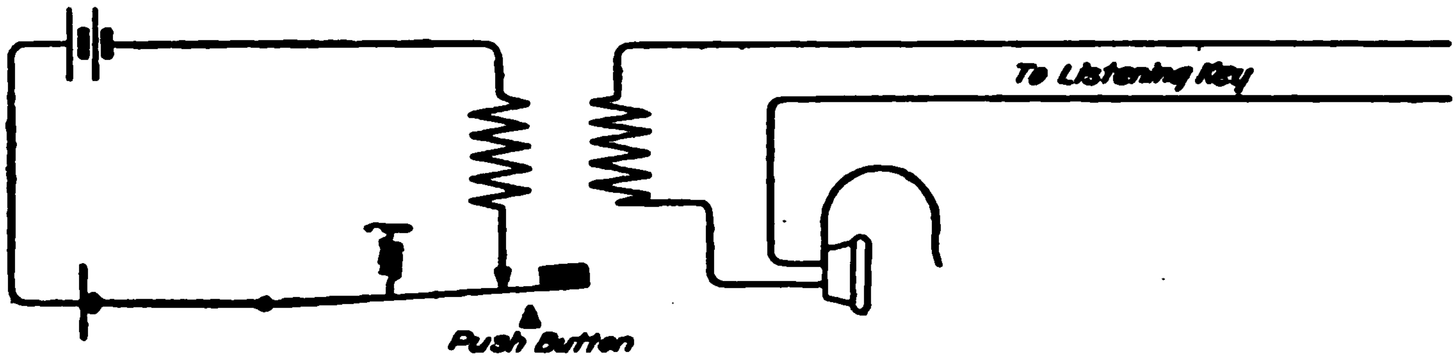


Fig. 19

normal position, keeps the primary circuit closed; but when pressed, opens the primary circuit and consequently no noise can then be transmitted to the line through the operator's transmitter.

Another method, which is shown in Fig. 20, consists of a push button connected across the secondary winding of the operator's induction coil. The circuit through the push button is normally open, but when the button is pressed, the secondary winding is short-circuited. The latter arrangement

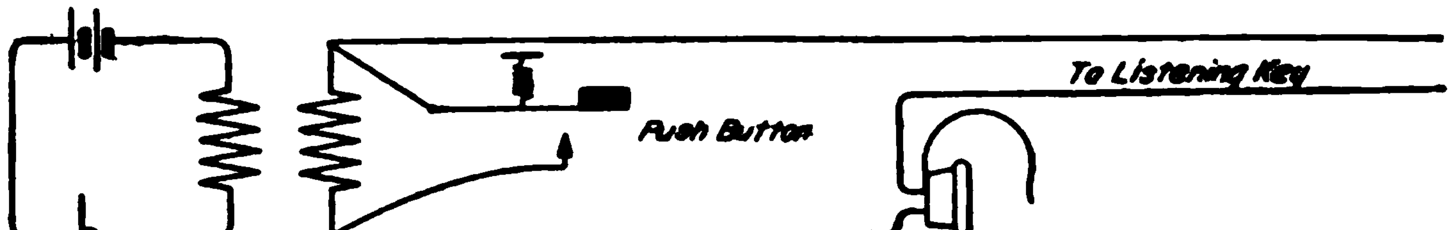


Fig. 20

ment is preferable to the former, because practically no clicks can be heard by the subscriber when the push button is pressed or released. In either case, the operator must, of course, release the push button, which may be mounted in some convenient position on the keyboard, while she is talking.

Still another method, which is used in some central-energy systems, is to connect a push button around the transmitter. The push button is normally open, but when pressed, short-circuits the transmitter. This produces less disturbance in other transmitter circuits than opening the transmitter circuit.

27. Manager's Night Listening Circuit.—It is sometimes difficult in a small or medium-size exchange to maintain discipline among the operators when neither the chief operator nor manager are on duty. To assist in maintaining an orderly operating room, an arrangement applied to any one of the operator's sets, whereby the manager at his home can hear everything that is going on in the exchange room, is very advantageous. One arrangement for such a circuit is shown in Fig. 21. In series with the operator's transmitter

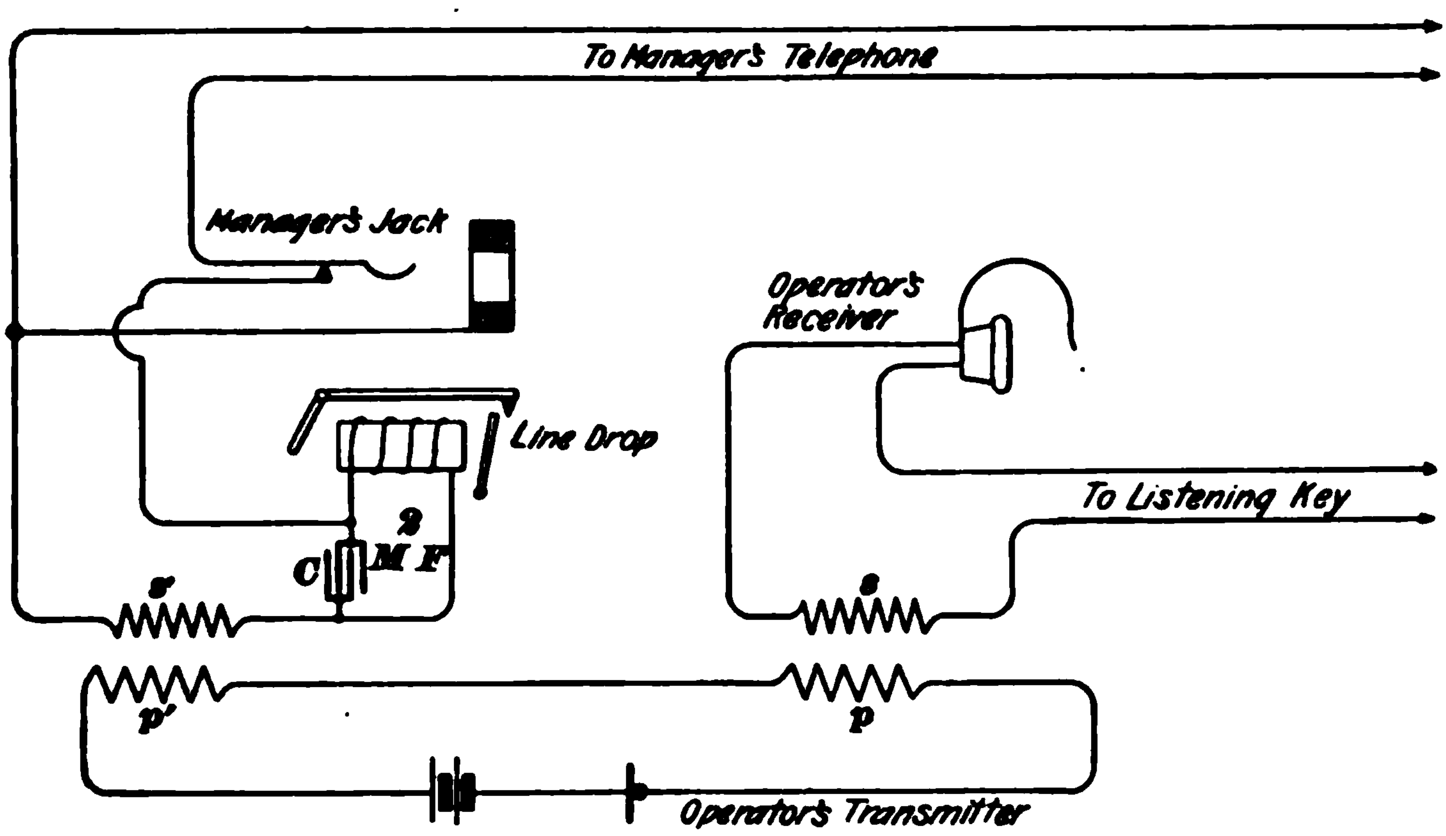


FIG. 21

and primary coil p, is connected another primary coil p'; and in the manager's line circuit is connected the secondary coil s'. Across the line drop is connected a 2-microfarad condenser C, which will not interfere with the operation of the line drop, but will enable the voice currents to readily pass around it. With the listening key opened or closed, every word spoken by any one in the switchboard room can be heard at the manager's telephone, which may be at his residence. He can thus listen in whenever he pleases, and

without any one in the exchange being aware of the fact. If the manager calls up the exchange, the line drop and secondary coil s' are cut out when the operator inserts a plug in the manager's jack. This is not intended as a spying system, but rather as a check on the operators, who, knowing of its existence, will attend more strictly to business.

HOWLER

28. An arrangement of apparatus and circuits that may be used to produce a howling sound in a subscriber's receiver that has been carelessly left off the hook, is termed a **howler**. The judicious use of a howler circuit will save the troubleman many trips, which frequently require a half day, merely to replace a receiver that has been carelessly left off the hook. It will be found that nearly always some one can be brought to the telephone when the howler current is thrown on the line, if they are in the same house, as the sound is very penetrating and strange, and any one who hears it will immediately investigate, and when they reach

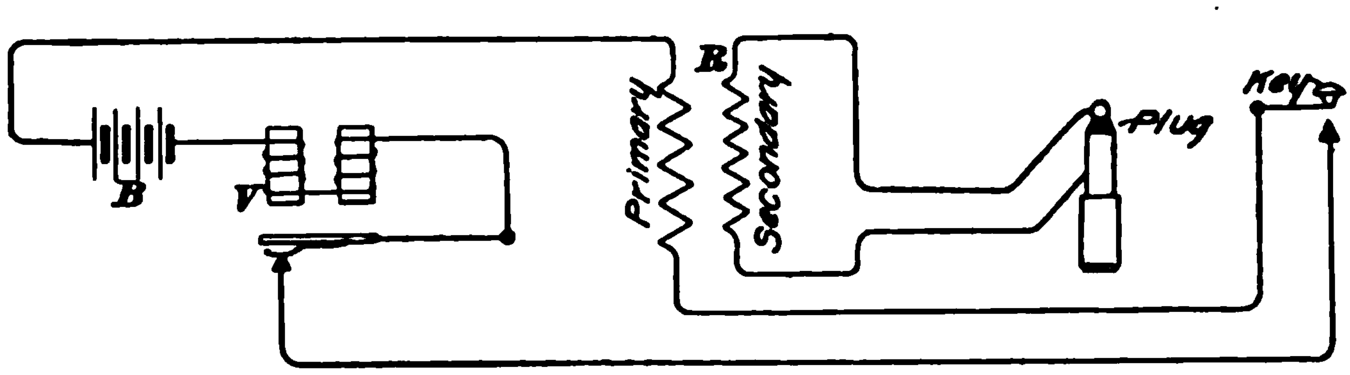


FIG. 22

the instrument will instinctively place the receiver back where it belongs. For this purpose, a mechanical interrupter is usually connected in series with a battery and the primary winding of an induction, or repeating, coil; the secondary winding of the coil is connected to the line of the subscriber in whose receiver the howling sound is to be produced.

A very simple arrangement that is suitable for use in a small exchange is shown in Fig. 22, in which V is a vibrating device that will periodically interrupt the current from the battery B. The interruptions should be somewhere between

about 100 and 800 per second, about 600 being preferable. An ordinary buzzer may answer the purpose. *R* is a repeating coil. When the key is closed and the plug inserted in a jack, the receiver will give out a humming sound due to the alternating current induced in the secondary winding of the repeating coil. Some howlers will produce a sound that can be heard at a distance of 100 feet from the receiver. By allowing the vibrator to run continuously and terminating the secondary circuit in a jack, it may be used for *busy back signaling*, which will be explained in connection with multiple switchboards.

29. In Fig. 23 is shown a howler circuit suitable for use in a large exchange where power is available for driving a commutator. *W* is an interrupting device consisting of a

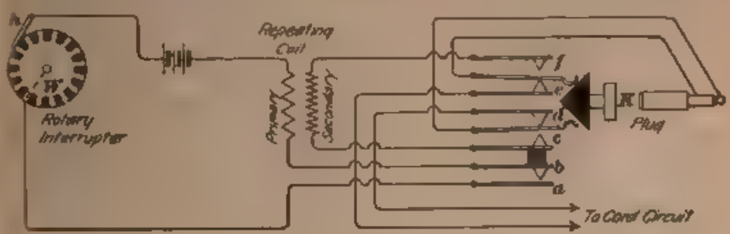


FIG. 23

metal wheel in the circumference of which are notches filled with hard insulating material, represented by the black segments. One side of the circuit to be periodically broken is connected to the metal wheel in any good way, for instance, through the metal support and shaft, and the other side of the circuit to a stationary brush *h* that bears against the circumference of the wheel. The circuit is broken and the current interrupted each time an insulating segment passes under the brush. This interrupting wheel is rotated by any suitable source of power, at the proper speed to produce a loud howl in a telephone receiver. In large exchanges, this interrupter is usually attached to and operated by the same motor that drives the ringing generator; and the current through the interrupter in central-energy exchanges is supplied by the exchange storage battery.

The howler key *K* is arranged so that the plug is normally connected to its cord circuit, the primary and secondary circuits of the howling device being open. To call a party whose receiver has been left off the hook, insert the plug in the jack of that subscriber's line and close the howler key, which connects the secondary winding through contacts *c*, *f* with the plug and disconnects at *d*, *e* the rest of the cord circuit. The primary circuit is only closed between contacts *a*, *b* when the key is closed, so that current flows from the battery only while the howler current is being used.

POLE CHANGERS

30. A **pole changer** is a device employed in telephone systems to rapidly interrupt or reverse a current from a battery in such a manner that it may be used to ring polarized bells. It is really an automatically operated interrupting or reversing switch, the speed being such as to give about 30 to 40 current impulses (15 to 20 in each direction) per second. Pole changers are used in small telephone exchanges where it is inconvenient or impossible to use a power-operated generator or where the pole changer would be the more economical to install and operate.

31. The **Warner pole changer** for ringing telephone bells is said to be working satisfactorily in over 2,500 exchanges in the United States alone; it is said to ring as many as forty telephones bridged across the same circuit and to be suitable for ringing series party lines. The diagram of connections of the standard Warner pole changer is shown in Fig. 24. The flat spring *s* tends to keep the contact spring *i* against the stop *f*. *T* is a small weight whose position along the arm may be varied, in order to vary the rate of vibration of the arm and thus produce an alternating current of the desired frequency at terminals *m n*. Enough cells are used in the ringing battery *R B* to give from 70 to 80 volts, usually requiring from forty to sixty Leclanché or dry cells, the former being generally used

for exchanges having over four hundred subscribers, and the latter for four hundred or less subscribers. Actual tests show that one ringing battery will furnish ringing current for one hundred subscribers for 18 months, for two hundred subscribers for 12 months, for three hundred subscribers for 9 months, and for five hundred subscribers for 6 months. A closed-circuit cell must be used at B, because it keeps

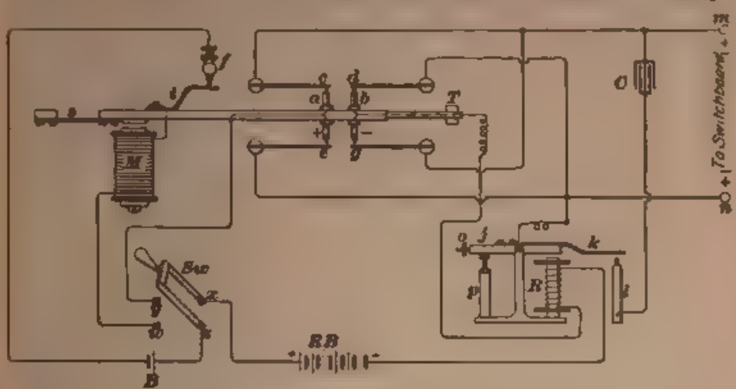


FIG. 24

the vibrating arm in motion continuously when the switch $S\,w$ is closed. Only one cell, such as an Edison-Lalande type R*, is required, and a cell of this capacity will operate the vibrating arm continuously (during the day) for 6 to 8 months. This cell should be placed near the pole changer to which it should be connected with wire not higher in resistance than

*The nine types in which Edison-Lalande cells are made differ only in shape or in size and capacity. They are listed as follows: type J, jar 3¾ in. × 7¼ in., 50 ampere-hour capacity, maximum efficient current 2 amperes; type Z, steel enameled jar 4½ in. × 6¾ in., 100 ampere-hour capacity; type BB, porcelain jar 4½ in. × 7¾ in., 100 ampere-hour capacity; type V, steel enameled jar 5¾ in. × 8 in., 150 ampere-hour capacity, maximum efficient current 3 amperes; type AA, steel enameled jar (about same size as R), 300 ampere-hour capacity; type Q, porcelain jar 5¾ in. × 8 in., 150 ampere-hour capacity, maximum efficient current 3 amperes; type R, porcelain jar 6¾ in. × 10 in., 300 ampere-hour capacity, maximum efficient current 4 amperes; type S, porcelain jar 5¾ in. × 13 in., 400 ampere-hour capacity, maximum efficient current 6 amperes; type W, porcelain jar 7½ in. × 15 in., 600 ampere-hour capacity, maximum efficient current 7 amperes. The cells put up in steel enameled jars are liquid tight and hence portable. The working voltage is about .65 volts.

No. 16 B. & S. copper. The ringing batteries may be set up at any convenient place.

32. Operation.—When no current flows from *RB* through *R*, the weight *o* is adjusted, so that it will keep the lever *j* against the stop *p*, and *k* is lifted off the contact post *l*. When the switch *Sw* is closed, current flows through *B–z–w–M–i–f*, thereby causing *M* to attract its armature, which is fastened to the vibrating lever; as soon as *i* parts from *f*, the current ceases and *M* releases its armature, thus allowing the circuit to be closed again between *i*, *f*. Thus the lever is kept vibrating, at about 15 to 20 complete vibrations per second, as long as *Sw* remains closed. When the operator closes the ringing key, current flows from $+RB$ through *x–y–a–c–m*–line–*n–d–b–R* to $-RB$, which causes *R* to attract its armature and close the circuit between *k* and *l*, thus automatically connecting the condenser *C* across the ringing leads *m*, *n* each time the lever closes the circuit between the line and battery *RB*. When *a*, *b* touch *e*, *g*, respectively, a positive current or impulse flows from *n* through the line and back to *m*; when *a*, *b* touch *c*, *d*, respectively, a positive current flows from *m* through the line back to *N*, thus giving, as indicated by the plus (+) and minus (−) signs, practically an alternating current in the ringing, or line, circuit.

The condenser is used for two reasons: first, to reduce the sparking when the circuit is broken between *a*, *e* and *b*, *g* or between *a*, *c* and *b*, *d*; second, to make the alternating-current wave smoother, which it does by absorbing some of the first rush of current when the circuit is abruptly made, and gradually giving up its charge when the circuit is abruptly broken. This reduces the induction that a sharply made and broken current would otherwise produce on neighboring circuits. It would not be well to connect the condenser permanently across the ringing leads *m*, *n*, because the constant charging of the condenser in alternate directions, when only *Sw* is closed, would be a constant drain on the ringing battery.

33. When the contact springs are properly adjusted, *c, d* should be about $\frac{1}{8}$ inch away from *a, b* when *a, b* are moved to one side until they just touch the springs *e, g*. If the vibrator stops while the switch *Sw* is closed, it is due either to an exhausted battery at *B* or to a dirty or worn-out contact on spring *i*. If the battery will ring an ordinary door bell, it is all right. If the battery is all right, the trouble is at the contact *i* and may usually be remedied by a slight adjustment of the screw *f*. However, if the contact point of *f* has worn a small dent in the platinum rivet on *i*, move the spring *i* so that the contact point will strike a new place on the rivet; in time, a new spring may be necessary. If the vibrator works, but still little or no ringing current can be obtained, either the ringing battery is exhausted or the wiring or brushes *c, d, e, g* are out of order. First, test the battery; each cell should ring an ordinary door bell. Then trace out the wiring, clean all joints, tighten binding posts, and see that the contacts *a, b* simultaneously strike the springs *e, g*, also the springs *c, d*. If the ringing current produces a noise on lines with which it is not connected, it is caused by too strong ringing batteries, or else the relay *R* is not working properly. The relay *R* should pull down its armature each time a call is made, and hold it down only as long as the ringing continues.

34. A view of the standard Warner pole changer, with similar parts lettered as in Fig. 24 and indicating also the proper way to connect it to local and toll switchboards and to the batteries, is shown in Fig. 25. To determine the number of cells required for the ringing battery, start with a small number and add cells, in series, until the bells on the longest lines and on the party lines having the greatest number of telephones can be rung with ease. If the current, which is determined in this way to be necessary for the toll lines, is too strong for the local lines, extra resistance (preferably non-inductive) should be inserted in the ringing circuits leading to the local subscribers' boards, as shown at *z*. It is also advisable to use a buzzer in each

switchboard circuit in order not only to indicate when lines are open, for the buzzer will not then ring, but especially to prevent excessive drain on the ringing battery due to a

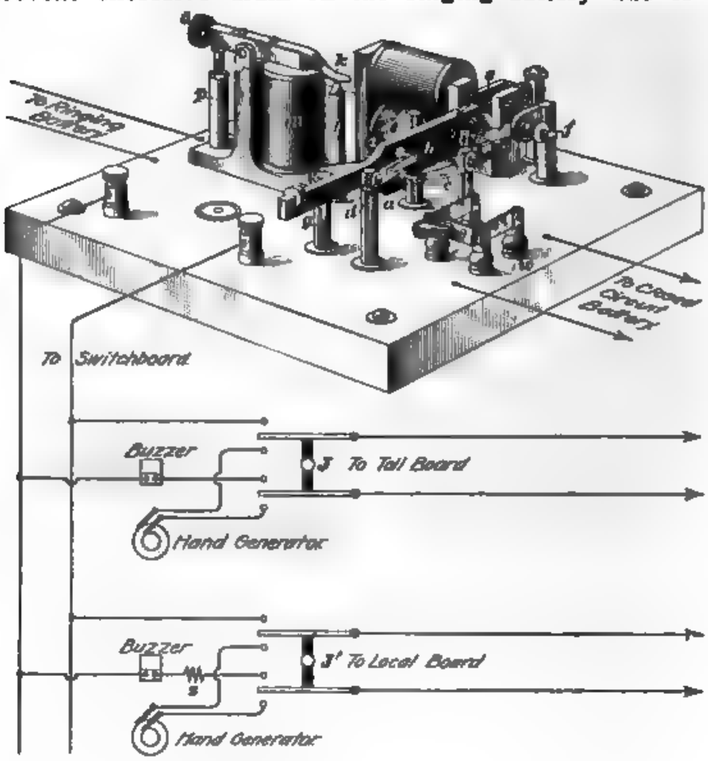


FIG. 25

short circuit on the switchboard and line side of the buzzer, which will cause it to ring continuously. To prevent exhausting the batteries, the short circuit should be immediately removed.

35. The **Warner selective pole changer**, a diagram of which is shown in Fig. 26, is the same as the standard machine, except that it has two extra contact pins *v*, *w* and two extra springs *x*, *u*. When *a* touches *e*, *w* touches *u*, and *b* touches *g*, and the switch *Sw* is closed, a positive impulse flows from $+RB$ through *l–j–k–a–e–n*–line–sub-

scriber's bell-ground or line-*m*, or through *a–w–u–z*-line-subscriber's bell-ground or other side of line to *m*, then through *g–b–R–l'* to $-RB$. When *a* touches *c*, *v* touches *x* and *b* touches *d*, then a positive impulse flows from $+RB$ through *j–k–a–c–m*-ground or line-subscriber's bell-line-*n–d–b*, or from *m* through ground, or one side of line-subscriber's bell-*y–x–v–b*, then through *R l'* to $-RB$. Thus, alternating current may be obtained through any circuit connected between *m* and *n*, or between *n* and the ground and positive impulses only in any circuit connected from *z* to *m* or the ground, and negative impulses in any circuit con-

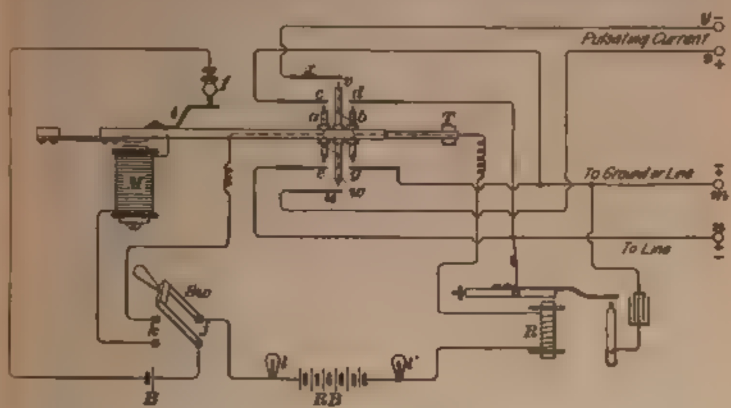


FIG. 26

nected from *y* to *m* or the ground. The selective pole changer, being slightly more complicated, is not recommended by the makers, unless party lines requiring plus and minus pulsating currents are used or are to be used in the future. To prevent any harm from short circuits and grounds, one 50-volt, 16-candlepower, incandescent lamp *l*, *l'* may be connected in the circuit on each side of and near the battery *RB*. Then even if the battery or either line wire becomes grounded, there will be at least one lamp in the circuit to prevent damage. Although requiring more cells, the lamps tend to make the strength of current in all circuits more uniform.

36. Illinois, or Sandwich, Pole Changer.—The diagram of connections of the pole changer said to have been made at one time by the Illinois Electric Specialty Company and later by the Sandwich Pole-Changer Company, is shown in Fig. 27 and the general appearance of the instrument in Fig. 28. The mechanism consists of an electromagnet *M*, vibrating arm and contacts, resistance *R*, and switch *S*. When *S* is closed, the magnet *M* is supplied with current from the closed-circuit battery *B* through the vibrating contacts *i*, *f*. Hence, the magnet *M* will keep the arm on which the springs *e*, *i*, *h*, *g* are mounted vibrating as long as *S* is closed. The spring *h* merely limits the forward motion of the arm. The resistance *R* is always in series with the battery *R B* to limit the strength of the current, and the condenser *C* is also always connected across the battery *R B* and resistance *R*. In the Warner pole changer, the condenser is connected across the ringing circuit by a relay only when some ringing key at the switchboard is closed and ringing current is flowing through some line circuit. Incandescent lamps are used in the Warner selective pole changer in the same manner as the resistance *R*.

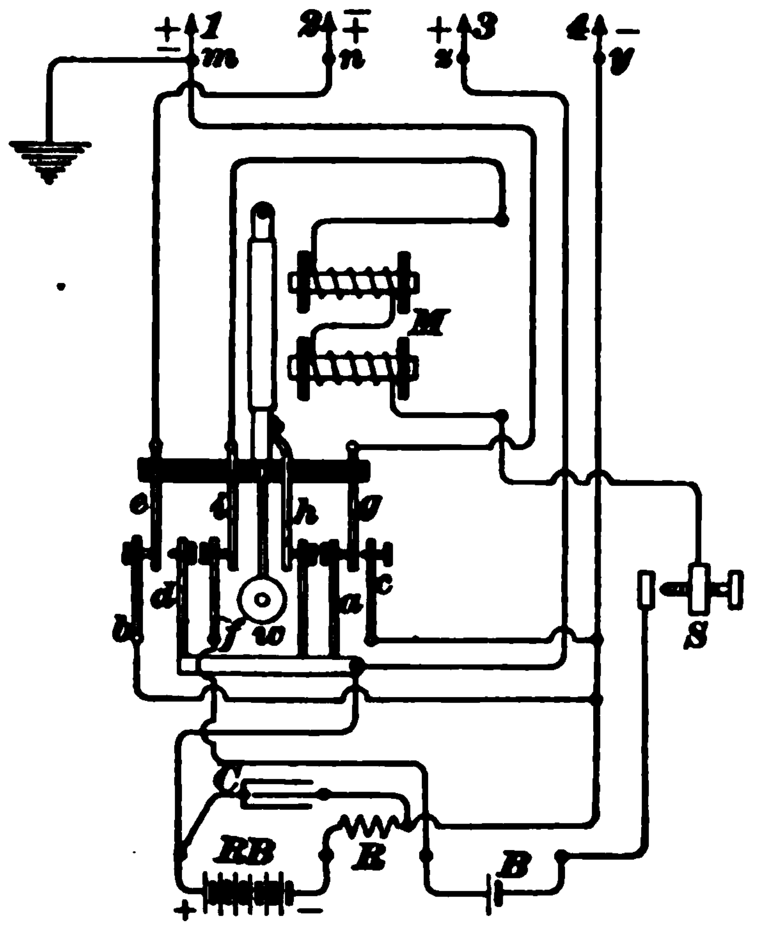


FIG. 27

37. Operation.—When the vibrating arm is in its extreme left position, the connections are as shown in Fig. 29 (*a*), in which three line wires are also shown. It will be seen that a current now flows from *m* to *n* through the complete metallic line *1*, from *m* through ground and line *3*, while no current is flowing in line *2* because the

ground connection practically short-circuits it. When the vibrating arm is in its extreme right position, the connections are as shown in Fig. 29 (*b*). A current now flows from *n* through line *1* [in the opposite direction to that shown in (*a*)], also from $+z$ through line *2*–ground to *m*, while no current is flowing in line *3*. In place of a ground return, the other side of lines *2* and *3* may be connected directly to *m*. Thus, a line connected across *m*, *n* receives current impulses in both directions, practically an alternating current that will ring ordinary polarized bells, a line connected from *y* to *m* or to the ground will receive negative current impulses separated by periods of equal length, during which no current flows in this line, and a line connected from *z* to *m* or to the ground will receive positive current impulses separated by periods of equal length, during which no current flows in this line.

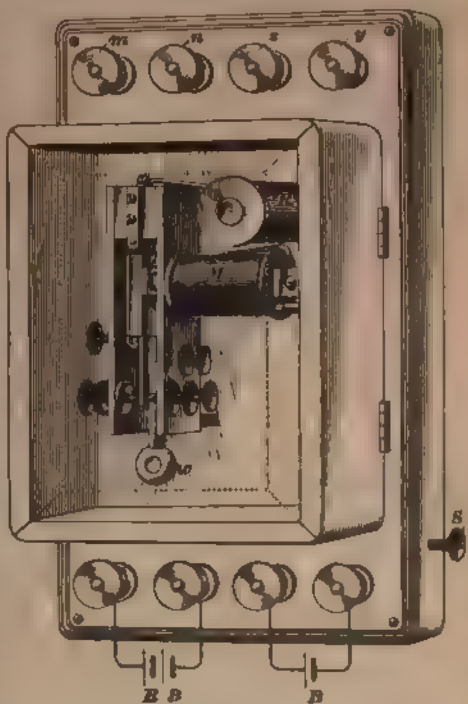


Fig. 28

All the figures relating to this pole changer are lettered alike to assist in following out the circuits. This pole changer is usually mounted on a wall or other vertical surface so that the vibrating arm hangs down. By varying the position of a small weight *w*, the frequency of the ringing current can be adjusted. Four dry cells are required at *B*,

just enough to properly magnetize the low-wound magnet *M*, but sixty-five or more dry cells connected in series are required at *R B* in order to furnish a strong enough ringing current through the highest resistance line and bell in use in any one exchange.

38. By varying the number of cells in the open-circuit battery of the pole changers so far described, the strength of the ringing current can be changed to suit local conditions. In exchanges using the Thompson four-party-line system, which requires a relay in each instrument for connecting the polarized bell in the circuit, it is necessary to have two rows of cells connected in multiple, as four relays have to be operated in addition to the polarized bell, thus requiring a larger amount of current. The first cost of a pole changer is less than that of a good magneto-generator with an electric or water motor to run it, and the low price at which dry cells may be bought makes the running expense less than any kind of outside power.

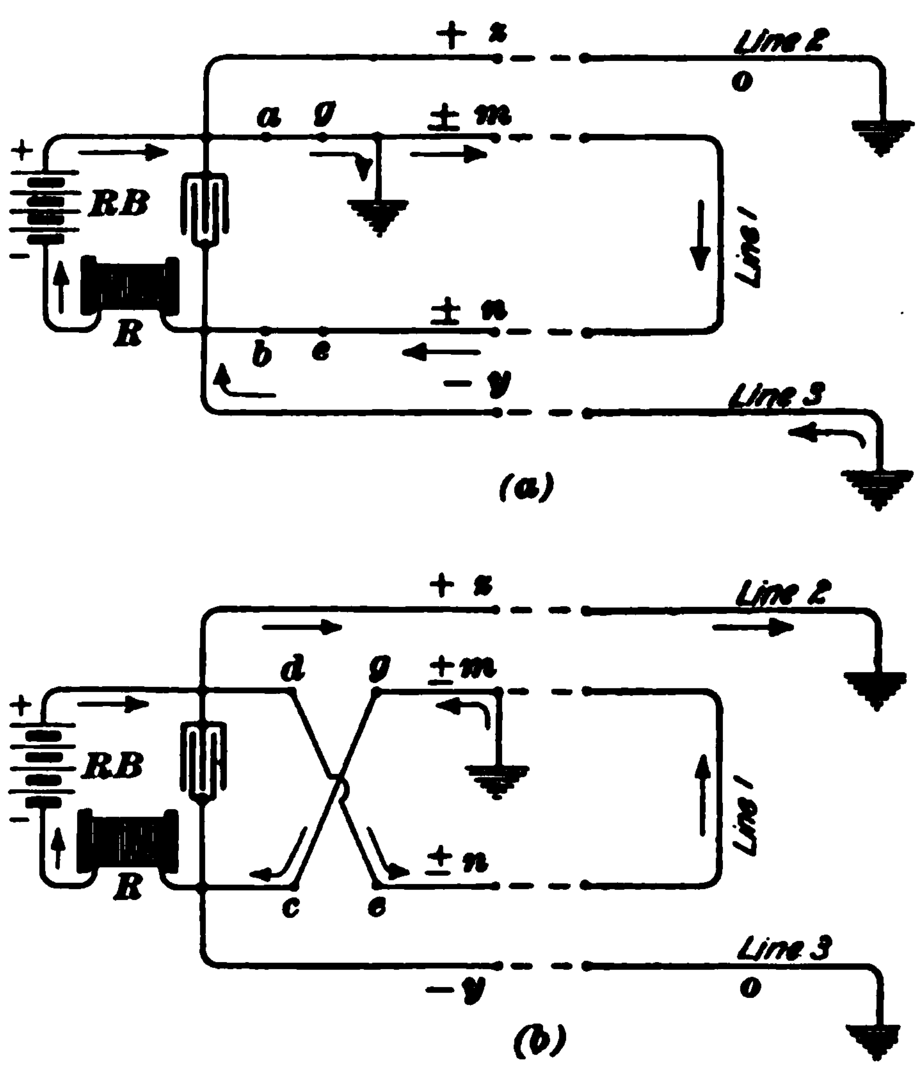


FIG. 29

39. Malthaner Generator.—The **Malthaner generator** seems especially suitable for use in private branch central-energy exchanges that are supplied with all current through a pair of wires from the main exchange. However, it is usually less trouble to supply the ringing current from the main exchange through a pair of wires; therefore, this is

the plan usually adopted unless there is no extra pair of wires that can be used for this purpose and the cost of a new pair is too great. This generator can be operated by connecting it directly to the battery terminals. It consists of a large coil, containing two windings, a primary and secondary, wound on the same soft-iron core, and a strong, U-shaped, permanent magnet.

The soft-iron core and the permanent magnet form a magnetic circuit, broken at one end by two air gaps between the end of the core and the two permanent magnet pole pieces. Across these special shaped air gaps, an armature of soft iron swings on a pivot; and as it swings, it moves a spring back and forth between two fixed contacts. The arrangement is such that the motion of the armature reverses the direction of a current supplied from a suitable battery through the primary winding around the soft-iron core, thus reversing the polarity of the iron core and the swing of the armature, which is therefore alternately attracted to and repelled from the respective poles of the permanent magnet and caused to vibrate rapidly. The reversal of the current thus produced in the primary winding induces in the secondary winding an alternating current of proper frequency and voltage for ringing ordinary telephone bells. Patent No. 791,277 was issued for this ringing generator to J. C. F. Malthaner about June, 1905.

40. Scribner Pole Changer.—In the **Scribner pole changer** (patent No. 760,574), a condenser or high non-inductive resistance is connected, by means of extra springs mounted on a vibrating arm similar to that used in a Warner pole changer, across the ringing-battery circuit just before it is made and disconnected just after it is broken. The sparking is thus reduced and the current curve made smoother without the extra relay used in the Warner pole changer.

41. An Automatic Pole-Changer Starter.—An automatic starter for a pole changer, which can be thrown into service at night when the calls are few, saves unnecessary

use of the closed-circuit batteries. Since it is difficult to call party-line subscribers, whose signals are distinguished by long and short rings, by using a hand generator, it is desirable, when the exchange possesses a pole changer, to also use it at night instead of the hand generator, as is customary in many exchanges. In Fig. 30 is shown an automatic pole-changer starter described in the American Telephone Journal. At *S* is shown a six-point circuit switch that it will probably be necessary to construct. When the night force is ready to assume duties, the chief operator should open the pole-changer switch *K* and close the six-point switch *S*, thereby throwing in the automatic starter and the night-bell circuit at the same time. When a subscriber rings, the shut-

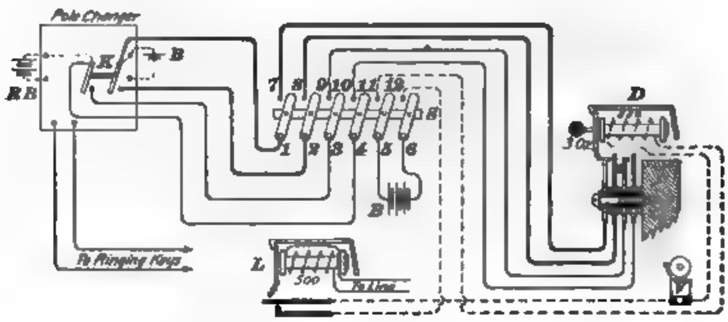


FIG. 30

ter of his line drop *L* falls and closes the night-bell circuit containing the night bell *V*, the special drop *D*, and the battery *B*. This will cause the night bell to ring and the weighted shutter of the drop *D* to fall, thereby closing the contact springs beneath it. When these springs are thus closed, current from the closed-circuit battery *B* can flow through and operate the pole changer, which then supplies the switchboard with alternating or pulsating current for ringing purposes from the battery *R B*.

After calling the party wanted and ascertaining that he has responded, the operator places the shutters of the drops *D* and *L* in their normal position, thereby restoring all circuits to their normal conditions. The operator, in order to secure

a ringing current at any time, has simply to let down any line drop L on the switchboard for a second. Before leaving in the morning, the operator in charge for the night opens the switch S and closes switch K on the pole changer, thereby leaving everything in condition to handle day calls. The connections of the pole changer, which are not shown in this figure, are assumed to be the same as those shown in Figs. 24 and 25; however, this starter may be arranged for use with almost any pole changer.

LARGE MAGNETO-SWITCH-BOARDS

TRANSFER SWITCHBOARDS

1. Thus far, only those switchboards for use in comparatively small exchanges, that is, those exchanges having not over four or five hundred subscribers, have been described. Under ordinary circumstances, the number of subscribers allotted to an operator during the busy portion of the day does not usually exceed one hundred and forty; but any one of these may desire a connection with any other subscriber on that same section, or a connection with any subscriber on any of the other sections. When the switchboard comprises but three or four sections, the connections between subscribers whose lines terminate at different sections are made by reaching across the face of the boards with the calling plug of the pair used in answering the call, and inserting it in the jack of the called subscriber. The extent to which this can be done is limited by the length of the cords, the sizes of the boards, and the reach of an average operator. The length of the cord is necessarily limited by the height of the switchboard above the floor, unless some special arrangement of pulleys is used for taking up the slack in the cords. Complication in the cord weights has, however, been found undesirable, as the room occupied by the cords is usually crowded, even under the most favorable circumstances, and the added complexity is a great disadvantage.

2. When the number of sections becomes so great that it is not economical to reach across with a pair of cords in

order to complete a connection, other means must be provided. One of these is to provide a system of auxiliary circuits, usually termed **transfer**, or **trunk, circuits**, running between the various sections of the switchboard, and provided with means by which the operator at each end may connect any one of these lines with the line of a subscriber. The transfer lines thus serve as an auxiliary connecting circuit between two subscribers' lines that cannot be well connected by a single pair of plugs and cords. A switchboard arranged to operate on this general principle is termed a **transfer switchboard.** In transfer switchboards, two operators are required to complete a connection between two subscribers, unless it happens that the line of the subscriber called for is within easy reach of the operator who answers a particular call. The term transfer switchboard is used in distinction to multiple switchboard, in which each line is provided with a jack on each section of the board, so that any operator will have within reach a terminal socket for every subscriber's line coming into that exchange, and will thus always be enabled to complete the connection between any two subscribers herself.

3. Transfer switchboards for large exchanges are rapidly going out of use, generally being replaced by central-energy multiple switchboards or by automatic telephone systems. Where it is necessary, however, to increase the capacity of a simple non-multiple switchboard already having three operators' positions, the most economical way, as far as first cost is concerned, is to add the necessary number of new sections and connect the various sections by simple transfer circuits. There is, however, a limit beyond which it is not desirable to continue to increase the size of an exchange in this manner. Furthermore, trunk circuits are extensively used between different switchboards located in the same or different buildings, whether they be transfer, multiple, or toll switchboards.

TRANSFER CIRCUITS

4. Where there are more than three operators' positions in a non-multiple switchboard, each position usually has transfer circuits to all non-adjacent positions, thereby providing a means of extending any subscriber's line to a remote position. The operator before whom a call originates is usually termed the *A*, or **originating, operator,** while the one completing the call is termed the *B*, or **incoming trunk, operator.** In small transfer and some other systems, the same operator may act as an *A* operator in connection with one call and as a *B* operator in connection with another call.

Either the *A* operator must tell the *B* operator the number of the desired subscriber or else the *B* operator must ask the subscriber to repeat the number. The first method is the more desirable.

5. Two ways of operating transfer and trunk circuits are in use. Both operators may bridge their talking sets across the transfer circuit and use it to give and receive orders. This is satisfactory for small and medium-sized transfer systems; but for large systems, the number of calls requiring the use of transfer or trunk circuits is so great as to render a separate circuit, called an **order wire,** economical. One order-wire circuit between several *A* operators and one *B* operator may be sufficient for a number of trunks from each *A* operator to the same *B* operator.

Communication between the operators is then made by means of order-wire circuits, into which an operator may switch her telephone set, in order to communicate with another operator and convey to her the desired information concerning the subscriber called for and the transfer line to be used.

6. Simple Transfer System.—The simplest method of running transfer lines between the sections of a switchboard, and one that is very often used, especially in cases where exchanges have become too large to be handled without transfer lines, is to run a number of lines between each of the boards, terminating these lines in spring jacks at each

end. If, then, a subscriber on section No. *1* calls for a subscriber on section No. *7*, the operator at board No. *1* will insert the calling plug of the pair used in answering the call into the jack of the transfer line leading to section No. *7*, and notify the operator at No. *7* of the connection desired. The operator at section No. *7* will then insert the answering plug of a pair into the jack at the other end of the transfer line used, and the corresponding calling plug into the jack of the subscriber called for. The connection will then be established between the two subscribers by means of a pair of plugs at section No. *1*, the transfer line itself, and a pair of plugs at section No. *2*. It is evident that this connection is effected through the use of four plugs and four jacks. In more improved systems, the number of plugs and jacks used in making such a connection is reduced sometimes to three, and even to two.

When each end of a transfer circuit is similarly equipped, say with a jack and a signal that may act as a call and disconnect signal, the trunk may be used in either direction; such a circuit is called a *two-way trunk*, or *transfer circuit*. When a trunk circuit is equipped so that it can be used in only one direction, say with a jack at the *A* operator's position and a plug and proper signal at the *B* operator's end, it is called a *one-way trunk*, or *transfer circuit*.

TWO-WAY TRANSFER CIRCUITS

7. Lamp-Signal Transfer Circuits.—Small, or miniature, incandescent lamps are now extensively used as signals in telephone switchboard circuits. In Fig. 1 is

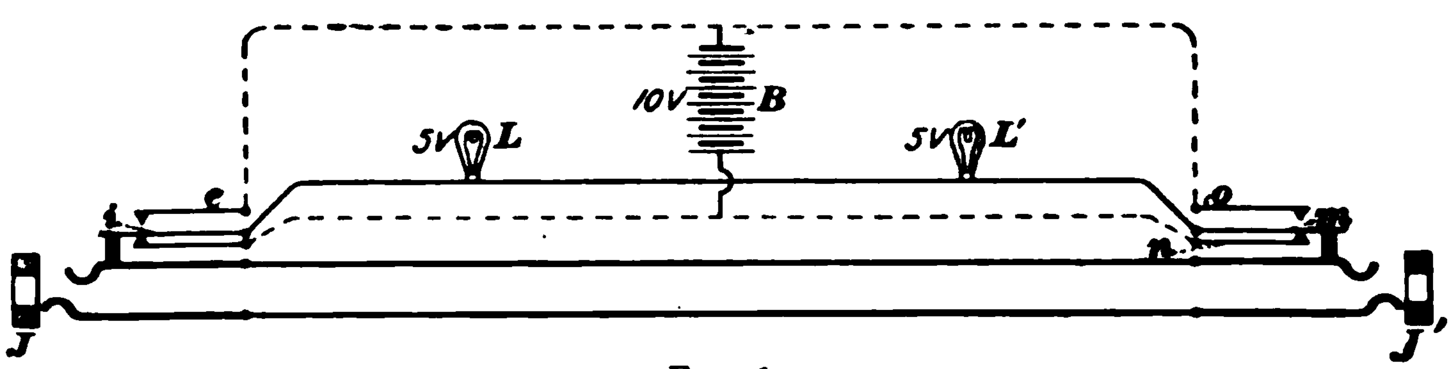


FIG. 1

shown a **two-way lamp-signal transfer circuit** suitable for use with magneto-switchboards. It terminates in a

small, incandescent, 5-volt lamp L and jack J at each end. B is a 10-volt battery of primary or storage cells. Both lamps L, L' are out when there is no plug in either jack or with plugs in both jacks.

The operator receiving the call answers in the regular way, and, after ascertaining the party wanted, inserts a plug in the transfer circuit leading to the position in which the jack of the wanted subscriber appears. This act lights a lamp at both ends of the transfer circuit, the one in the remote position serving as a signal for the second operator, who answers and completes the connection between the two subscribers. For instance, when a plug is inserted in jack J, current flows through B-c-i-L-L'-m-n-B, thus lighting both lamps. When the second operator answers, by inserting a plug in J', the lamp circuit is opened between m and n and both transfer lamps are extinguished. The subscribers ring off in the regular way, operating clearing-out drops in both positions. When either operator pulls down the connecting cords, both signal lamps of the transfer circuit illuminate and remain in this condition until the other operator disconnects, when both lamps will be extinguished. Thus the lamps serve as a check on each operator's action and prevent any possible "tying up" of the connected subscribers on the transfer circuit.

The dotted lines in this and the following two figures represent conductors that may be used as common leads to similar points in all similar transfer circuits.

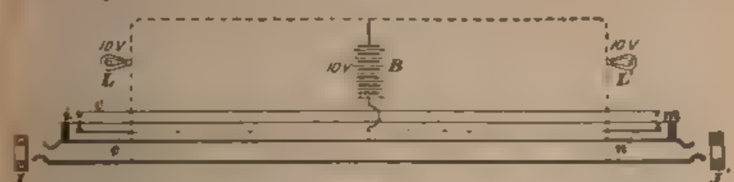


FIG. 2

8. Lamps in Parallel.—In the transfer circuit just described, the two lamps are in series and the voltage required for each lamp is half that of the battery. A slightly different arrangement, whereby the lamps are in parallel circuits, is shown in Fig. 2. Lamps of the same voltage as

the battery and an extra wire, six in all, are required for this arrangement, which operates in exactly the same manner. When a plug is in *J*, current flows through *B*–*L*, *L'* (in parallel)–*e*–*i*–*m*–*n*–*B*. When plugs are in both jacks, the battery is cut off at *v*, *n*. The Kellogg Switchboard and Supply Company use a transfer circuit in connection with their express switchboards that is practically the same as the one shown in this figure.

9. Lamps and jacks for transfer circuits are frequently made in strips of five, and are mounted just below the line drops and jacks. The current for 10-volt transfer lamps may be obtained from seven standard Fuller cells. A suitable number of transfer circuits would be five between each position and every other non-adjacent position, this would make fifty trunks having twenty transfer jacks and signals at each end position and fifteen at each intermediate position on a six-section board of about one hundred subscribers' lines each. The same total number of transfer circuits would allow about four between non-adjacent positions for a seven-section board.

10. Two-way transfer circuits can be used in either direction and furthermore no order-wire circuits are required, because the operator can converse over the transfer circuit to be used. A two-way transfer circuit usually has the disadvantage of requiring the second operator to ring up the desired subscriber, instead of leaving the entire supervision of the call to the first operator, and in using two complete cord circuits in the completed connection.

ONE-WAY TRANSFER CIRCUITS

11. Lamp-Signal Circuit.—The **one-way lamp-signal transfer circuit**, shown in Fig. 3, eliminates the disadvantages of the two-way circuit, but can only be used in one direction, thus necessitating more transfer circuits and requiring an order-wire circuit between all non-adjacent operators for ordering up connections. The order-wire

circuit is not shown here. The outgoing, or originating, end of the transfer circuit is provided with a spring jack *J*, while the connecting end is provided with a cord and plug *P*, a disconnect lamp *L*, and a plug-seat switch *S*. In making transfer connections, the originating operator presses the order-wire key (not shown in this figure); this will connect her talking circuit directly with that of the operator at whose position such line terminates. Either operator may specify the transfer circuit to be used, depending on the system in vogue: in either case the second operator simply inserts the transfer plug *P* into the required line jack, and the originating operator rings the subscriber and has direct supervision of both parties. When the first operator pulls down

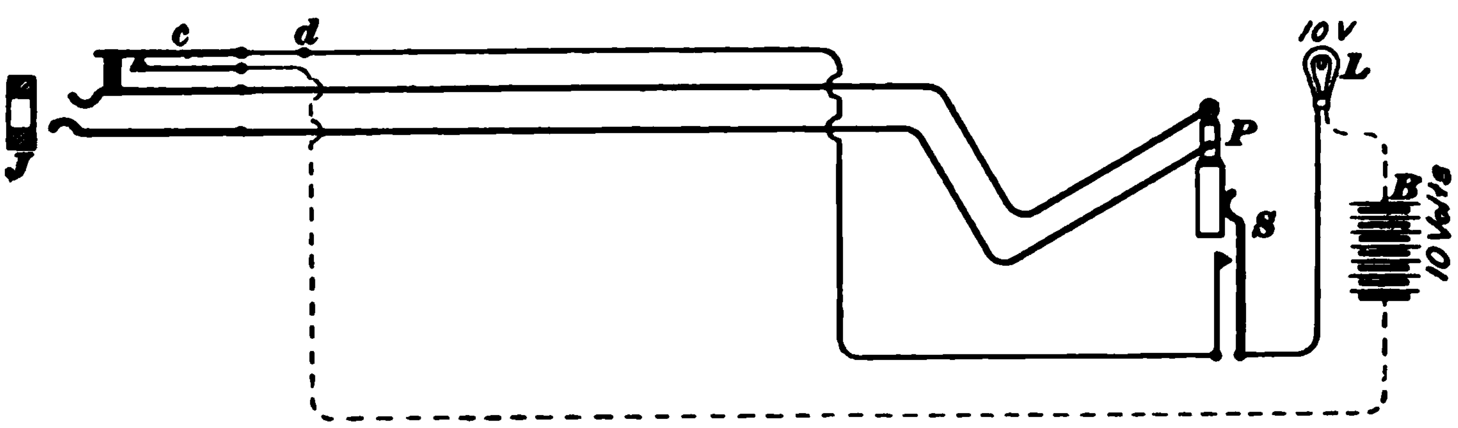


FIG. 3

the cord circuit, the local contact *c* of the outgoing transfer jack *J* will be closed, causing the disconnect lamp *L* at the second operator's position to light. The dropping of the transfer plug *P* into its seat opens the switch *S*, thereby extinguishing the disconnect lamp.

If a lamp signal that will work in unison with the lamp *L* is desired at the originating end, it is only necessary to insert a 5-volt lamp in series with *L* at the point *d*, a 5-volt lamp also being used at *L*; that is, the battery *B* must give twice the voltage of either lamp. From the operating standpoint, one-way transfer circuits are the most efficient of the two, although the first cost is greater because more are required.

12. Where one end of a transfer circuit terminates in a plug-and-lamp signal, these parts are often arranged on the key shelf of a switchboard, as shown in Fig. 4. In the back

row are the answering plugs *a*; in the second row, the calling plugs *c* of the regular operator's cord circuits; in the third row, the transfer plugs *t*; and in front of each transfer plug is the corresponding disconnect lamp signal *s*. At *d*, *d* are

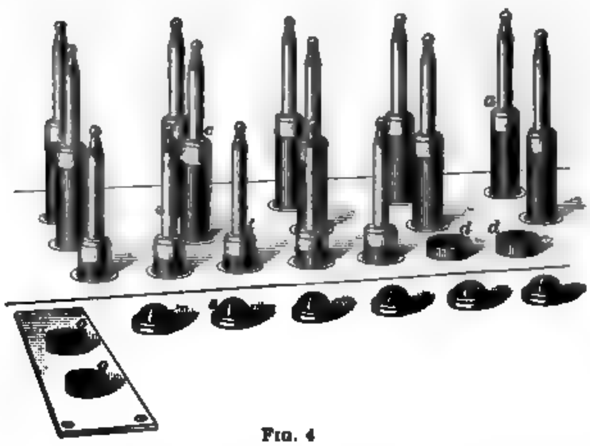


FIG. 4

caps covering holes for transfer plugs not yet required. The lamps are covered with glass opals and metal guards. At *o*, *o* are shown two order-wire keys, which operate like ordinary push buttons.

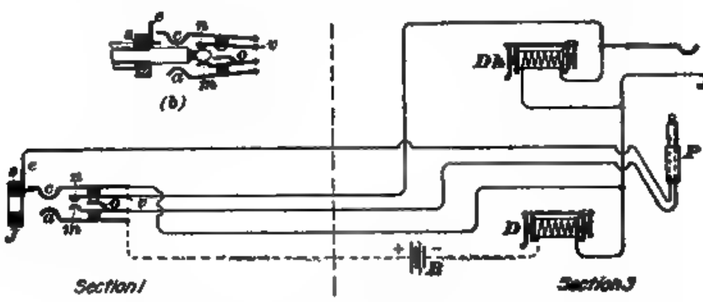


FIG. 5

13. The **Cook, or Cook-Beach, transfer circuit,** which is considerably used by some of the Bell companies and the Sterling Electric Company with magneto-switchboards, is shown in Fig. 5. If a call is received at a certain section,

say section *1*, for a connection that is out of reach of the operator at that section, she inserts a plug in the transfer jack *J*. As the plug slides into the jack, the tip touches and momentarily connects together the two springs *a*, *c*, thereby closing the circuit of the battery *B* through the drop *D*, and giving the signal to the operator at the section where the called-for subscriber's line terminates in a jack, say section *3*. At the same time, the operator presses an order-wire button opposite the jack *J*, but not shown in this figure. This connects together the telephone circuits of the operators at sections *1* and *3*. The number called for is then given by the first operator and is received through the order-wire circuit by the other operator.

After the tip of the plug passes the two springs *a*, *c*, it not only makes electrical contact with *m*, but pushes the two springs *m*, *n* farther apart, thereby separating the springs *a*, *c*, so that they do not touch any part of the plug and also separates *c* from *e*. This position of the plug and springs is shown at (*b*). The tip of the spring *n* is provided with a piece of insulating material to prevent electrical contact between the spring *v* and the tip of the plug. The plug at section *1* is now connected through sleeve *s* and spring *m*, directly with the plug *P*.

14. The second operator, seeing the shutter of the drop *D* down, picks up the plug *P* corresponding to it and inserts it into the desired subscriber's jack and restores the shutter of *D*.

The first operator then rings the bell of the desired subscriber; the two subscribers can now converse through one transfer and one cord circuit. When either subscriber rings off, the clearing-out drop in the cord circuit at section *1* will operate, thus notifying the operator at that section to disconnect. When she removes the plug from the jack *J*, the springs *a*, *c*, being momentarily connected together again, operate the drop *D*, thus notifying the operator at section *3* to remove the transfer plug *P* from the subscriber's jack.

15. It sometimes happens in transfer systems that after ringing off or before the conversation is finished, the connection between the two subscribers is broken at one of the boards only. This may leave the other subscriber's line without an available signal, so that that subscriber cannot attract the attention of the operator, no matter how much he may ring. Such a condition as this might exist if the drop *D* failed to operate when the operator at section *1* removed the plug from jack *J*. The subscriber's drop at section *3* would be cut out at his line jack by the plug *P* and he would have no means of calling central. A line in this condition is usually said to be ***tied up*** or ***hung up***.

In order to provide against this, the Cook system provides a drop *Dh* for each transfer circuit. The current that operates *Dh* flows from the subscriber's generator through the tip of plug *P*–springs *o*, *v*–drop *Dh*–spring *c*–contact *e*–sleeve of plug *P*–generator. When the shutter of a hang-up drop falls, the operator inserts one of her ordinary answering plugs in the hang-up jack *Jh* and inquires, "Who called." When told, she withdraws the plug and makes the connection called for.

In case the shutter *D* does not fall, the trouble is usually due to poor contact with springs *a*, *c*, to defective battery, or to a bad drop. If *Dh* does not work, look for the trouble in the jack *J*, at contacts *c* or *e*, or in the drop itself. As *Dh* is bridged across the circuit of the jack *Jh*, this drop should have a high impedance, so as not to interfere with transmission when talking through the trunk circuit.

TRUNK CIRCUITS BETWEEN EXCHANGES

16. Transfer circuits of the character so far described are simple, efficient, and suitable for small transfer systems; but, they require a complicated jack and four or more wires. For a few transfer circuits short in length these disadvantages are not important; but for long transfer circuits, generally called *trunks*, the first cost and maintenance of so many wires for a single circuit is prohibitive and has led to other arrangements.

17. The principle of operation of so-called **reverse-call trunking systems,** now extensively employed between large exchanges, will be explained by the aid of Fig. 6. The

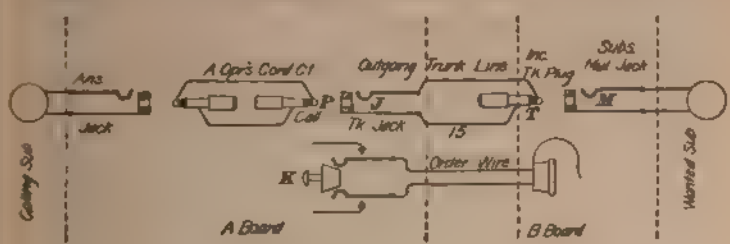


FIG. 6

trunk ends in a jack J at the A board and in a plug T at the B board. If any A operator receives a call for a line out of her reach, she touches the button K of an order wire that extends to a B operator before whom the desired line appears. For a moment, the A operator listens to determine if any other A operator is speaking; when she finds the circuit clear, she speaks the number of the subscriber desired. Where records are kept of such connections, the A operator states the numbers of the calling and called-for subscribers, thus 86 to 915, and one or both operators keep full records of such connections. The B operator replies by speaking

the number of an idle trunk that the *A* operator is to use. The *A* operator then inserts her calling plug *P* in the trunk jack *J*, designated by the *B* operator, which usually operates a signal at the *B* end of the trunk. The *B* operator then inserts the same numbered incoming trunk plug *T* into the jack *M* of the desired subscriber's line. The whole operation is completed in 2 or 3 seconds.

The same method may be used for clearing out; that is, when the subscribers' disconnect signals appear, either operator may use a call wire to order the other to disconnect. But a less confusing and better method that is now generally used consists in equipping trunk lines with disconnect signals so arranged that when an *A* operator, who alone receives the disconnect signal, removes a plug from a trunk jack, a signal is automatically given to the *B* operator to disconnect.

ORDER-WIRE CIRCUITS

18. **Order-wire circuits** are used in connection with transfer, or trunk, circuits between different sections of the same transfer switchboard and also between entirely separate switchboards. An order-wire circuit usually extends from across the secondary and receiver circuit of a *B* operator to the normally open contacts of several keys located before as many *A* operators. Any *A* operator, by closing her key, can always talk directly to the *B* operator. A similar circuit may connect the same two positions in the opposite direction. As there are one-way and two-way trunk circuits, so there are *one-way* and *two-way order-wire circuits.*

ONE-WAY ORDER-WIRE CIRCUIT

19. In Fig. 7 is shown a **one-way order-wire circuit** suitable for use with almost any kind of trunk circuits.

Where there are many sections, the same order-wire circuit may have a number of keys located at different sections bridged across it, as shown in this figure. Thus, a number of operators have access to the same operator through the same

order-wire circuit. There is nothing to prevent two or more *A* operators from coming in at the same time on the same order wire, except their own common sense and good judgment. The *A* operators are instructed to listen in to determine whether the order wire is clear, before speaking to the *B* operator. It might appear that utter confusion would result,

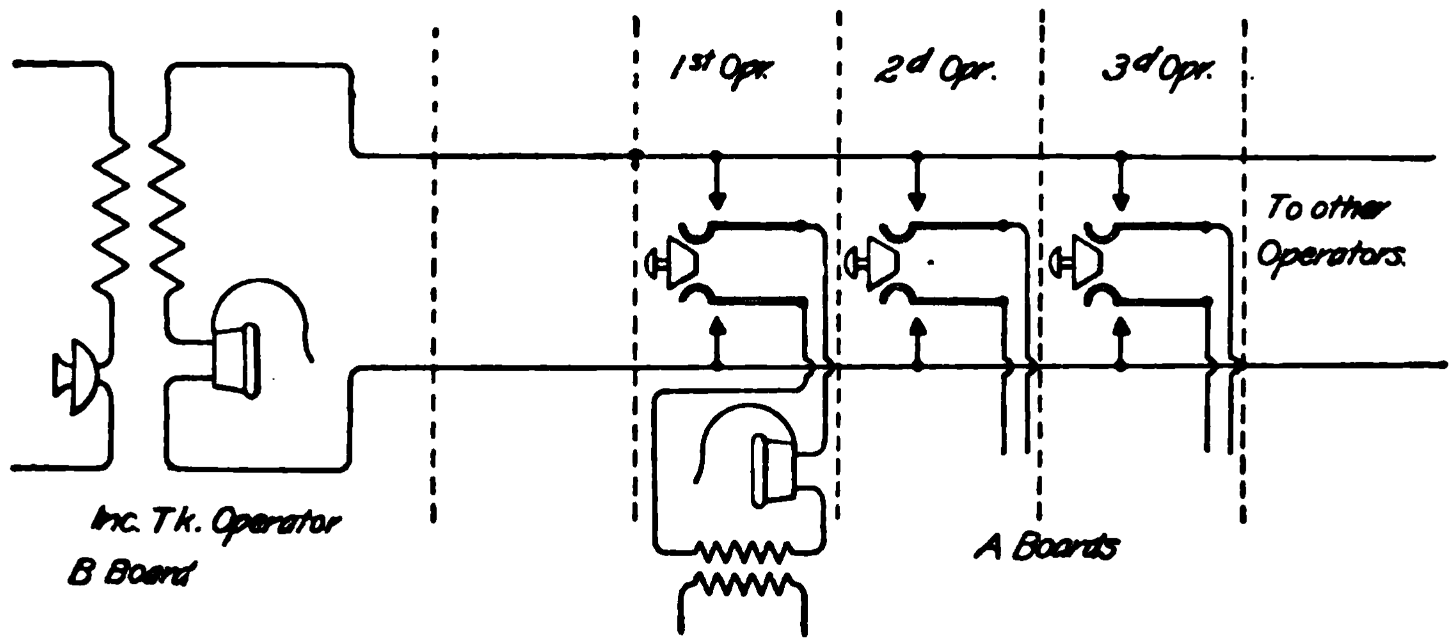


Fig. 7

but experienced operators find no difficulty with the system. Each operator must refrain from interrupting another, just as they would do if engaged in conversation face to face.

20. In Fig. 8 is represented the arrangement of order-wire circuits for a six-section transfer switchboard, one line

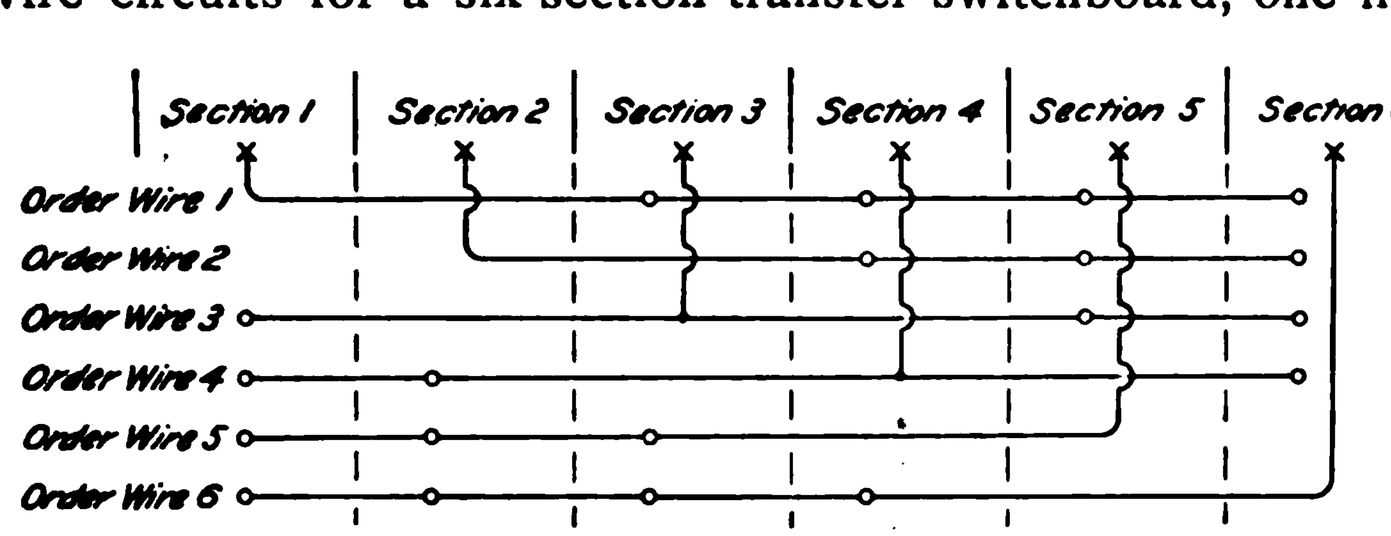


Fig. 8

being used to represent a complete circuit. The small crosses represent operators' receiver circuits, one being permanently bridged across each order wire. Each order wire has connected across it an order-wire key, represented by the small circles, at each operator's position that is not adjacent

to the position where the receiver circuit is bridged across it. Thus, each end position requires four and each other position requires three order-wire keys. By this arrangement, each operator can talk to any other operator at non-adjacent positions through an order-wire circuit. Since an operator can reach over and complete connections on adjacent sections, no means of communication with adjacent operators is required.

TWO-WAY ORDER-WIRE CIRCUIT

21. The **two-way order-wire circuit,** shown in Fig. 9, which was designed and described by J. B. Middleton,

FIG. 9

in the American Telephone Journal, is said to have proved satisfactory between a multiple switchboard and a branch

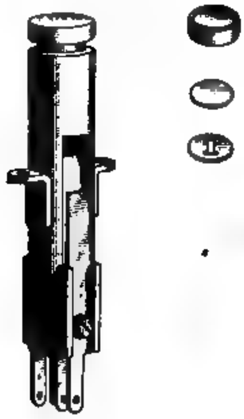


FIG. 10

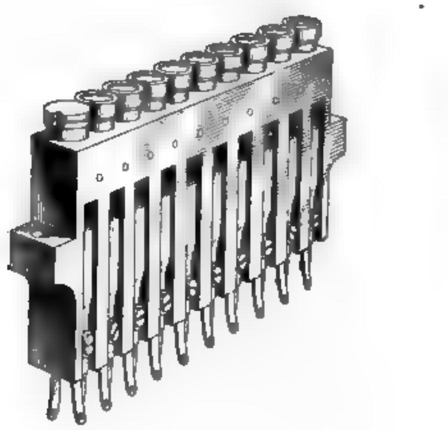


FIG. 11

exchange. A relay is required at each end, and if the system is not a common-battery one, dry batteries will serve

the purpose, provided both batteries have about the same voltage. The batteries and relays are at the centers of the repeating coils, and hence the system is well balanced.

The operation of the circuit is as follows: Normally, the batteries oppose each other, and therefore no current flows through the relays r, r'. If either of the keys k, k' is pressed, the two batteries will be connected in parallel and current from both batteries will flow through the closed key, causing the armatures of both relays r, r' to be attracted. This will cut the operators' telephone sets into the circuit through the repeating coils. As there are no grounds on any part of this order-wire circuit, it will be free from earth currents.

22. Order-wire keys are usually made single or in groups of five or ten. In Fig. 10 is a single order-wire key and in Fig. 11 a row of ten made by the Kellogg Switchboard and Supply Company. The latter are provided with removable number caps, as shown.

THE MULTIPLE SWITCHBOARD

MAIN FEATURES

23. In the **multiple switchboard**, transfer, or trunk, lines between the operators are dispensed with, the primary object of the system being to so arrange the apparatus that any operator can connect the line of a calling subscriber with that of any other subscriber whose line terminates in the same exchange without the aid of another operator. The entire board is divided into sections, each usually containing working room for three operators, and on each section is placed, besides the annunciators and jacks of the lines, the calls of which are to be attended to at that section, the jacks connected with every other line in the exchange. The number of line signals placed on one section varies from 200 to 540, depending on the type of switchboard and other conditions. In an exchange having 5,000 subscribers, it follows

that twenty-five sections of board, each having two hundred line signals, would be necessary. Associated with each line signal is an answering jack, into which the operator inserts an answering plug, in order to connect her telephone with a line on which a call is indicated.

24. It is common practice in large cities to divide each section into three operators' positions, with an operator at each position during the busy part of the day. Each operator can reach over one division on each side of her own.

In the branching switchboard made by the Western Electric Company, there are fifteen pair of plugs, one listening and two ringing keys for each plug circuit, and a jack for each subscriber's line entering the exchange at each operator's position. Room is provided for one hundred annunciators and the corresponding answering jacks at each position, although seldom more than sixty to seventy-five are installed and in use.

On the central-energy multiple switchboards of the Bell Company, each operator attends to the lines of 140 to 180 subscribers, a great increase over the customary number per operator's position, even with the self-restoring annunciator board, which runs from sixty to seventy-five. With the central-energy board, the supervision over the lines in use and the number of movements required of each operator is considerably reduced, thus reducing the cost of operation as well as the initial cost of the switchboard by being able to reduce the total number of sections almost one-half.

25. In multiple switchboards, the answering jack is invariably placed directly over or under the line signal. In order to have the multiple jacks complete and arranged the same at each section, it is considered best to have, in addition to the answering jack, a jack associated with the same line but located in its regular position among the multiple jacks, which are usually placed above the answering jacks and line signals. Therefore, at the section where a certain line signal is located, there are two jacks associated with that

line. In other words, each answering jack is duplicated in the multiple portion. Hence, if there are 420 line signals to a section, there will be 420 more jacks at each section than there are line circuits coming to the whole switchboard, and each line will have one more jack than there are sections to the switchboard. In addition to the multiple and answering jacks, others are required for trunk lines to other parts of the exchange.

26. Multiplicity of Jacks.—In order that a jack connected with every line in the exchange may be within the reach of every operator, it follows that there must be a separate jack on every one of the sections for every one of the lines. Thus, if there are 5,000 lines on a 25-section switchboard, on each section having 200 answering jacks there will be a total of 5,200 jacks, making a grand total for the entire exchange of 130,000 spring jacks. When it is considered that in modern exchanges the connection of each of these jacks involves the making of five or more soldered connections, and that the wire and other materials and apparatus necessary are increased accordingly, it will be appreciated that the increase in expense over the transfer system is enormous. It may be stated that this increased expense has in most cases seemed justifiable in the best exchanges the world over, in view of the greatly increased efficiency of service.

27. An idea of the general plan of a multiple switchboard may be obtained from the simple diagram shown in Fig. 12, in which L, L', and L'' represent three subscribers' lines, each passing through jacks j, j', and j'' on the various sections A, B, and C of a multiple board. The drop D and answering jack J of line L are located at section A, and, in like manner, the lines L' and L'' are equipped with answering jacks J' and J'' and drops D' and D'' at sections B and C, respectively. If the subscriber L sends in a call, his drop D will attract the attention of an operator at section A, who will answer it by inserting one plug of a pair into the answering jack J at that section, and finding that the connection

desired is with line L' or L'', will insert the remaining plug of the pair into the jack j' or j'' of the line wanted. It is not difficult to understand that inasmuch as every line throughout the whole exchange is provided with a jack on section A and on every other section also, the operator at A will have means within her own reach of connecting the line L of the calling subscriber with any other subscriber's line coming into that exchange.

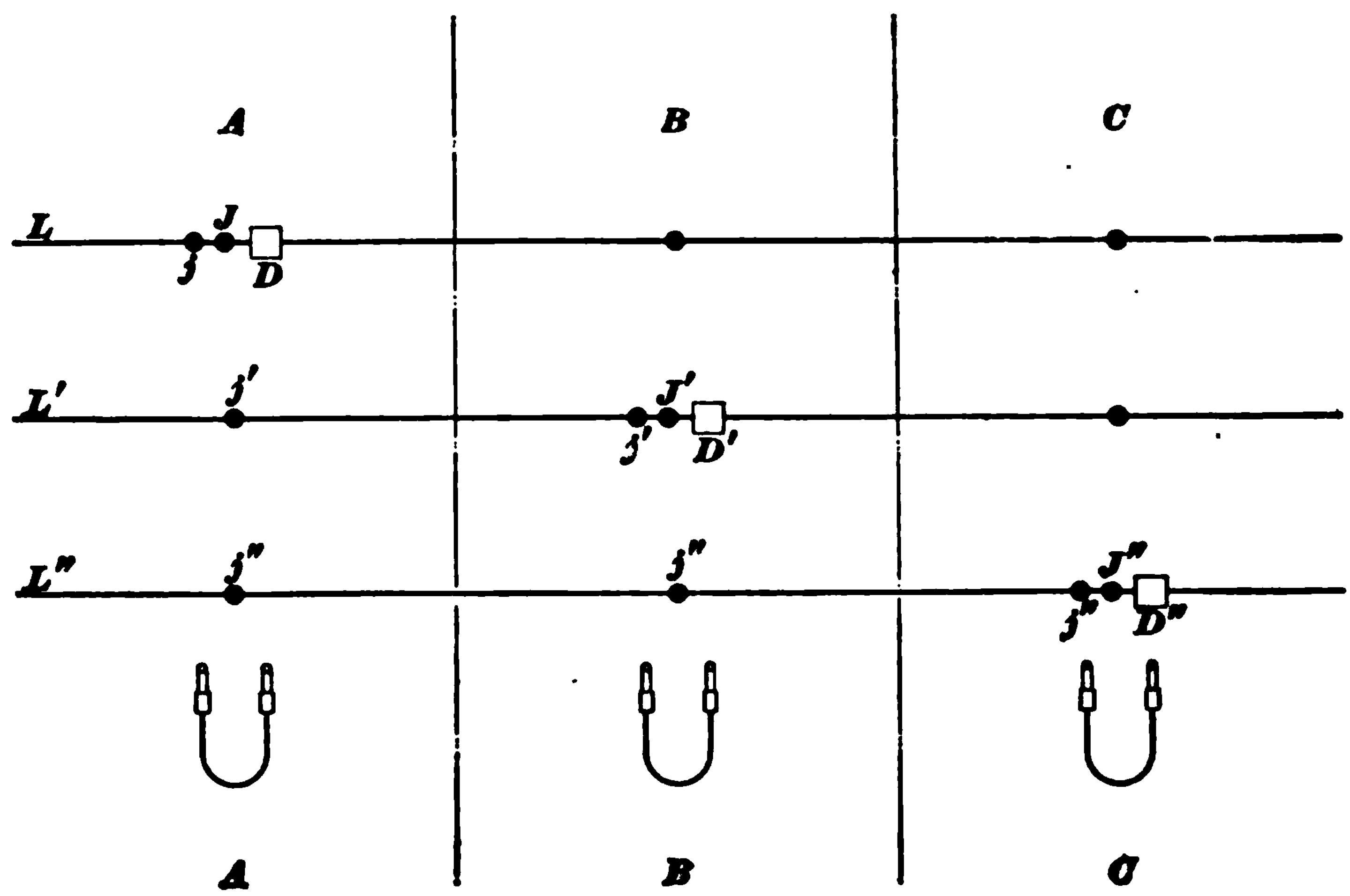


FIG. 12

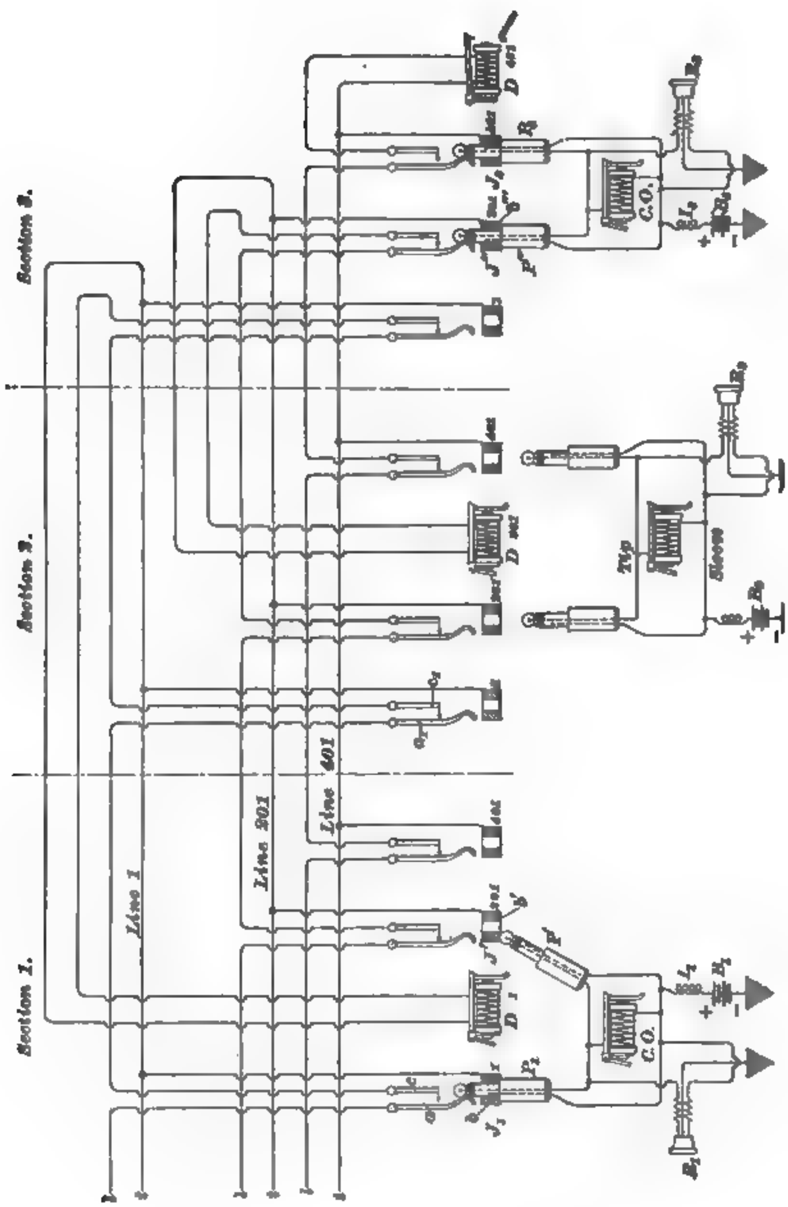
28. The Busy Test.—In order to understand the necessity for a busy test in multiple-switchboard systems, assume the lines L and L' to be connected together at the central office, as just described. Suppose that while they are so connected, subscriber L'' sends in a call. His drop D'' at section C will be thrown, and the operator at that section will place herself in communication with him by inserting the answering plug of a pair into the answering jack J'' of his line. Suppose, further, that this subscriber desires to be connected with line L'. It is evident that the operator at section C will, unless special means are provided, have no means of knowing that the line L' is already connected with another line at another section of the board. Should she,

therefore, connect the line L'' with the line L', the three subscribers would be connected together and much confusion would result. In order to prevent an operator from making connection with a line which is already in use at another board, there is employed the so-called **busy test**, which forms an essential feature in every multiple switchboard.

29. The test for a busy line is usually performed by the operator applying the tip of the calling plug of a pair, or *test plug*, as they are termed in multiple switchboards, to the thimble of the jack of the subscriber called for. If the line is busy, she will hear a click in her telephone, while if it is free or disengaged, silence will inform her to that effect. In some exchanges, this order is reversed, a click indicating a free line and silence a busy one, but this is unusual. The details of the busy test can only be understood in connection with the complete circuits of a multiple switchboard.

THE SERIES-MULTIPLE BOARD

30. Circuits. In Fig. 13 is shown diagrammatically three line circuits passing through sections of a multiple board. If there are 200 annunciators and corresponding answering jacks at each section, the annunciator $D\,1$ and answering jack J_1 for the line *1* would be located at section *1*; annunciator $D\,201$ and its corresponding answering jack *201* at section *2*, and so on, as shown in the figure. Of course, there would be 199 more annunciators and answering jacks at each section, and, in addition, one jack for each line coming into the exchange at every section. For the sake of clearness, only three lines are shown. Such an arrangement of circuits as that shown in Fig. 13 represents what is termed the **series-multiple board**, the term series being derived from the peculiar way in which the lines pass through the spring jacks at the various sections. The side l of the line *1* passes to the line spring a of the spring jack at section *1*, thence to the anvil c on which this spring rests, and by a continuation of the line wire to the spring a_1, and to anvil c_1 of the jack at section *2*, and so


Section 1.
Section 2.
Section 3.
Line 1
Line 201
Line 401
C.O.
C.O.
Tip
Sleeve

on through a jack at each section to one side of the line drop *D 1*. The other side *t* of the line passes unbroken through each section of the board to the other terminal of the drop, and is connected with the sleeve contact *b* of each jack belonging to that line. One pair of operator's plugs connected by a cord circuit is shown in this figure at each section. The cord circuit is greatly simplified in order to illustrate the principles rather than the actual arrangement of parts. The sleeve side of the cord circuit, at section *1*, for instance, is connected through an impedance coil I_1 to one terminal of a test battery B_1, the other terminal of which is grounded. The operator's telephone set R_1 is represented as connected across the cord circuit with its center grounded.

When a subscriber (say No. *1*) sends in a call, the current from his generator passes over the line wire *l* to the spring *a* of the first jack, then to the anvil *c* and to the spring a_1 of the second jack, and so on through the drop *D 1* and back to the subscriber's station over the line *t*, called the *test side* of the line *1*. This operates the drop, and the operator answers in the usual manner. The insertion of the plug into the jack raises the spring *a* from its anvil, and thereby cuts off that portion of the line circuit that passes through the succeeding sections and the drop; and at the same time, by means of the thimble *b* and the spring *a*, the two sides of the cord circuit are connected, respectively, with the two sides of the line.

31. Test.—At each of the three sections of the multiple board shown in Fig. 13 are located the annunciator, and alongside of it the answering jack of one subscriber, and of course one jack for each of the other two subscribers. If subscriber No. *401* turns his generator, his drop *D 401* located at section *3* falls, and the operator there inserts the answering plug P_3 into his answering jack J_3 *401*. If subscriber No. *401* asks for No. *201*, the operator, finding that line *201* is not already engaged, by a test to be presently explained, inserts the other plug P''' of the same pair into

the jack J''' *201* of that line, which is at her section of the board, and the connection is completed. The calling is done, in the ordinary manner, by sending a current from a generator through line *201*.

The test to find out whether or not a line is busy is performed by the operator touching the tip of the calling or test plug to the thimble b of the jack with which she desires to make connection. Suppose that line *401* is connected with line *201* at section *3* by the cord circuit and plugs, as shown at section *3*, Fig. 13. It is evident that one terminal of the test battery B_s will be connected through coil I_s, sleeve of the plug P''', and thimble b''' of jack J''' *201*, with the test side of line *201*, and, in fact, with the test side of line *401* also, and therefore to all the test thimbles of the various jacks of these two lines at all sections. This will raise the potential of the test thimbles of the busy lines above the ground by an amount equal to the voltage of the battery. Suppose, now, that the drop D *1*, located at section *1*, falls. The operator at section *1* inserts the answering plug P_1 into the answering jack J_1 *1*, and, having learned that subscriber No. *1* desires to converse with subscriber No. *201*, she proceeds to determine whether line *201* is engaged or free, by touching the tip of the other plug P' of the same pair to the thimble b' of jack J' *201*, and since line *201* is connected to line *401* at section *3*, she will obtain a click in her receiver, due to a current flowing from the test thimble b' through one-half of her receiver to ground. This will inform her that line *201* is busy, which fact she will communicate to the calling subscriber. The circuit from the test battery, through the operator's receiver, causing the click mentioned, may be traced as follows: from the positive pole of the battery B_s through impedance coil I_s–sleeve of plug P'''–thimble b''' of jack J''' *201*–test line t–thimble b' of jack J' *201*–tip of plug P'–half of receiver R_1–ground to the negative pole of battery B_s. If no previous connection had been made with line *201* at section *3*, or at any other section, the thimbles of that line would be at the same potential as the earth, and when the operator at section *1* applied the tip of her test plug P' to

the thimble b' of jack $J'201$, she would receive no click, and would know that line *201* was free.

32. A better type of jack for a multiple board is shown in Fig. 14. This jack insures a rubbing contact between both line wires through the springs a, c and the tip and sleeve of the plug, respectively. Furthermore, when a plug is inserted in a jack, the drop and all the jacks of that line at all sections beyond the one where the jack is inserted, are entirely cut out. Therefore, no wire, jacks, or drops beyond the jack in use are left in the circuit. In the preceding system of wiring the jacks and drops, the charging and discharging of the open branch by a variable current in the closed part of the same circuit often cause troublesome noises and cross-talk in the neighboring circuits in the switchboard cable. The insertion of the plug breaks the contact, as stated above, between springs a and d and between c and e, and thus avoids this trouble by opening both sides of the circuit beyond the jack. The spring f is permanently connected to a test wire, and when no plug is in the jack this spring connects with the thimble b. When a plug is inserted, the spring f is pushed against the grounded stop g. In this arrangement, the test battery is connected between the middle of the receiver coil and the ground. If the line is in use at section *1*, as shown, and the tip of plug P' at section 2 is touched to the thimble b', a current will flow in the following circuit: test battery B' –thimble b'–spring f'–test wire–spring f–stop g–ground–test

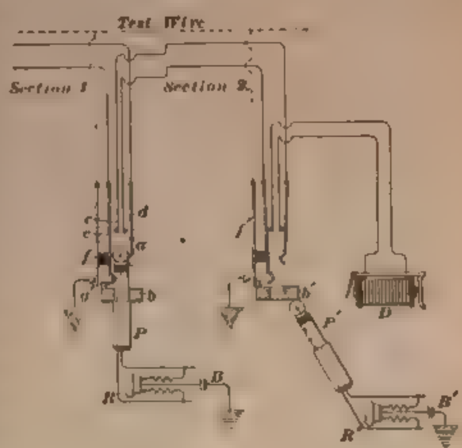


Fig. 14

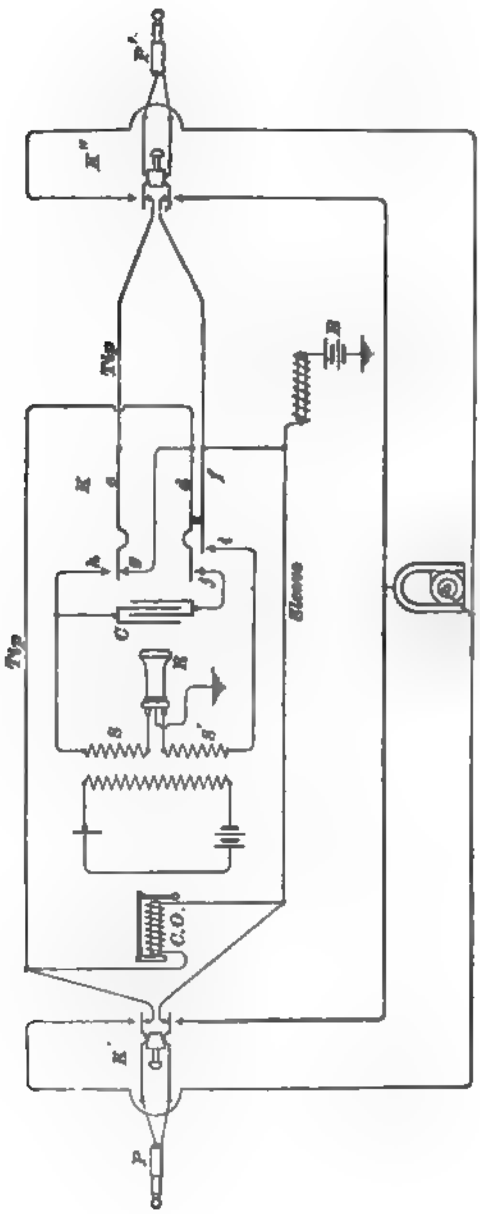


FIG. 15

battery B'; and produce the busy-test click in receiver R'. As the rest of the system, including the cord circuit, may be exactly the same as in Fig. 13, no further description will be necessary.

33. Cord Circuits.—Many arrangements of cord circuits have been used with boards of this type, but the one shown in Fig. 15 is typical. P represents the answering plug and P' the calling or test plug. K is a listening key, adapted when depressed to connect the operator's telephone set with the cord circuit. K' and K'' are ringing keys, normally preserving the continuity of the cord conductors, but adapted when depressed to connect the tip and sleeve strands of their respective plugs with the terminals of the calling generator. The operator's key K is provided with three springs d, e, and f. The spring e is connected with the tip strand of the test plug P' and normally maintains contact with the anvil g, thus completing the circuit between the tips of the answering and test plugs. This spring, when the key is depressed, is forced into contact with the anvil h, forming one terminal of the operator's telephone circuit. The sleeve strand of the cord is continuous, but is connected with the spring f of the key, which, when the key is depressed, is forced into contact with the anvil i, forming the other terminal of the operator's circuit. The spring d is permanently connected with the anvil g, and is forced by the depression of the key into engagement with the terminal j, thus introducing the condenser C into the tip side of the cord circuit. The secondary coil of the operator's telephone set is divided into two parts, S and S', and connected in the circuit on each side of the receiver. The receiver winding is also divided into two equal parts, the center point being permanently grounded, as shown. By grounding the center portion of the receiver in this manner, the balance of the line is better preserved than would be the case were one side of the circuit connected to the ground.

34. When the operator desires to communicate with the calling subscriber, she inserts the plug P into the jack of

his line and depresses the key K. This connects the sleeve strand of the cord with one terminal of her talking set at the point i, and connects the other terminal of her talking set through the condenser C with the tip strand of the cord at the point j. This circuit is shown in simplified form in Fig. 16. The condenser C, which is included in the circuit between the calling subscriber and the operator, allows the passage of the rapidly fluctuating voice currents set up by the transmitters associated with the circuit, but prevents the flow of a continuous current, from the battery B, over the same circuit to ground through the receiver. The operator's transmitter T is connected in a local circuit with a battery in the same manner as at the subscriber's station,

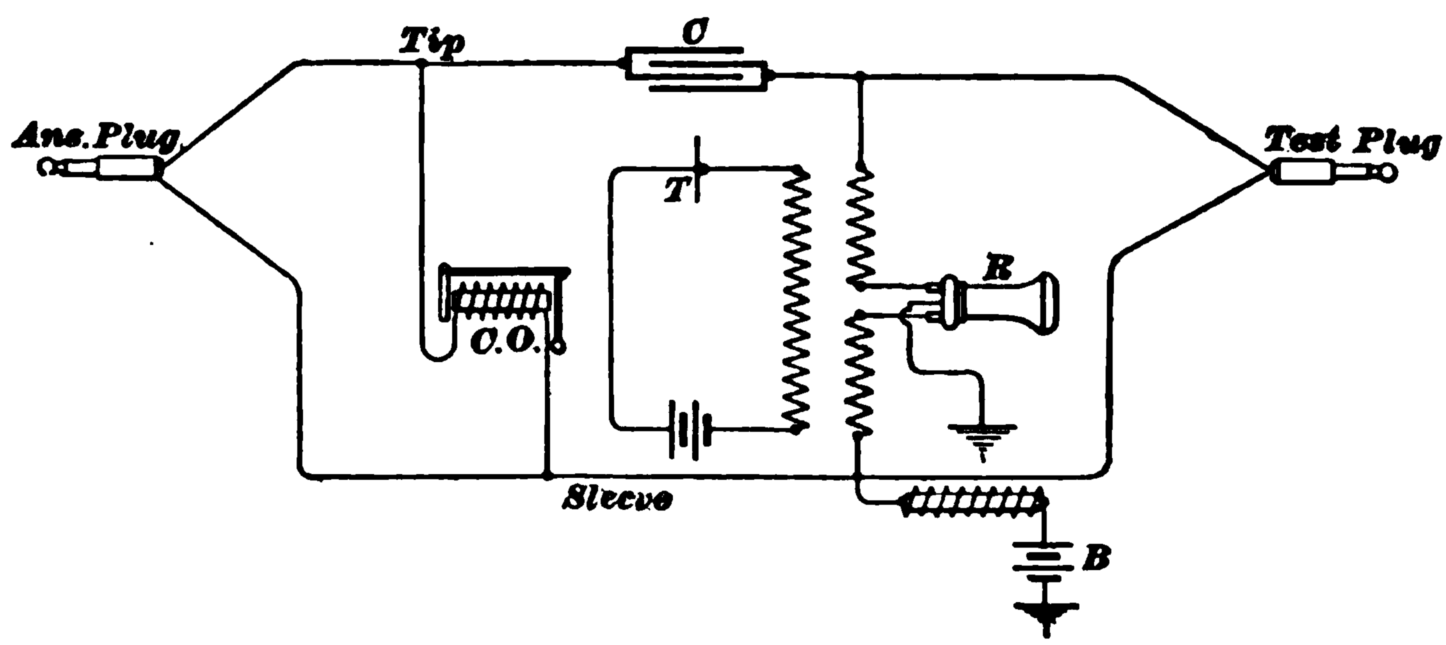


FIG. 16

the primary coil acting inductively on the two secondary coils in series. The depression of the key K, Fig. 15, that establishes the connection between the operator and the calling subscriber, also connects the tip strand of the test plug P' with one terminal of the operator's telephone set, this connection being brought about by the spring e engaging the anvil h. When the operator learns the number of the subscriber called for, she retains the key in this position and applies the tip of the test plug to the thimble of the jack of the subscriber called for, to determine whether the line desired is busy or free. If the line is not in use, the thimble of the jack will not be raised to a potential above that of the ground, and therefore no current will flow to ground from the

thimble of that jack through the tip of the test plug and the operator's receiver, and silence will result. If, however, the line of the subscriber called for is already in use, the thimble of its jacks will be raised to a potential above that of the ground, and a current (see Fig. 17) will flow through the tip of the test plug, the secondary coil S, and one-half of the operator's receiver coil to ground, thus producing a click.

35. Simplified Test Circuit.—The test circuit may, perhaps, be more readily followed by considering Fig. 17, in which b and b' represent the test thimbles of a line that is called for, the thimble b' being that of a jack at the section where the test is to be made, and the thimble b being that of a jack of the same line that is in use, but at some other section. If the line is busy, the test battery B will be connected to the test thimble b by means of the sleeve strand of the plug at that section. When, therefore, the testing operator applies the tip of her test plug to the thimble b, a current will flow from the battery B to the thimble b, thence to the thimble b', and to ground through one of the secondary coils S and one-half of the receiver coil, and thence back to the battery B. If, however, no plug is inserted in the thimble b, it is evident that there will be no closed circuit for a current from the test battery B through the receiver, due to the application of the test plug to the jack b'.

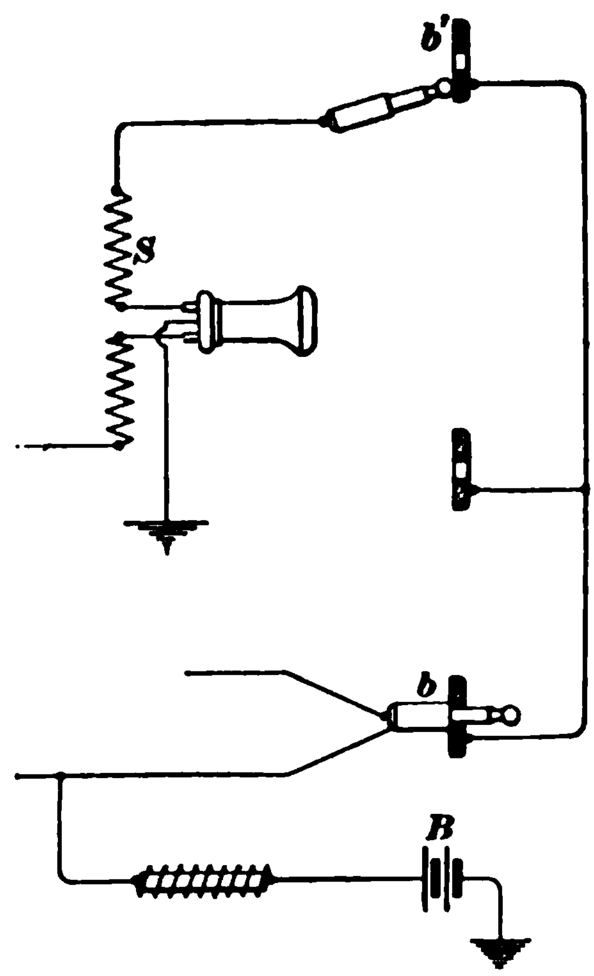


FIG. 17

36. Reach of Operators.—The clearing-out drop is included in a bridge circuit across the tip and sleeve strands of the cord circuit, and its operation needs no description. In boards of this kind, it has been customary to place the annunciators of two hundred lines on each section of the board, and to provide room at each section for three

operators. During the busier parts of the day, therefore, each operator would be required to answer the calls of sixty-six lines. It has been said that each operator has within her reach a jack connected with every line in the entire system, and that each section of the board is provided with a jack connected with every line. The center operator of the three at each section may readily reach all the jacks on that section, and therefore all the lines in the exchange. The left-hand operator at each section cannot reach the jacks on the right-hand third of that section, but she can reach the jacks on the right-hand third of the next section at her immediate left; as these are the duplicates of those on the right-hand third of her own section, she may connect with them in the same manner as if they were on her own section. In a similar manner, the right-hand operator of each section cannot reach the jacks at the left-hand third of her own section, but may make connection with those on the left-hand third of the section at her immediate right. In this way, all the operators are provided with means for reaching every line, even though three operators occupy positions in front of each section. At the extreme right and left ends of the whole switchboard, it is necessary to duplicate the jacks only of a third of a section, so that the end operators of the last complete end sections will still be within reach of all jacks.

37. Objections to the Series-Multiple Board.—The multiple board described has been widely used, but is nevertheless subject to very grave defects. In a system of 5,400 subscribers, having fifteen sections, the line wire will necessarily pass in series through a pair of jack-contacts at each one of these sections. A particle of dust or a loose contact in any one of these jacks will produce an open circuit, thus disabling the entire line—an occurrence that cannot easily be avoided. Moreover, among other objections, this particular system does not lend itself readily to the use of self-restoring line drops and clearing-out signals, and therefore the work of the operators is rendered more arduous, and the number of lines an operator can attend to is correspondingly reduced.

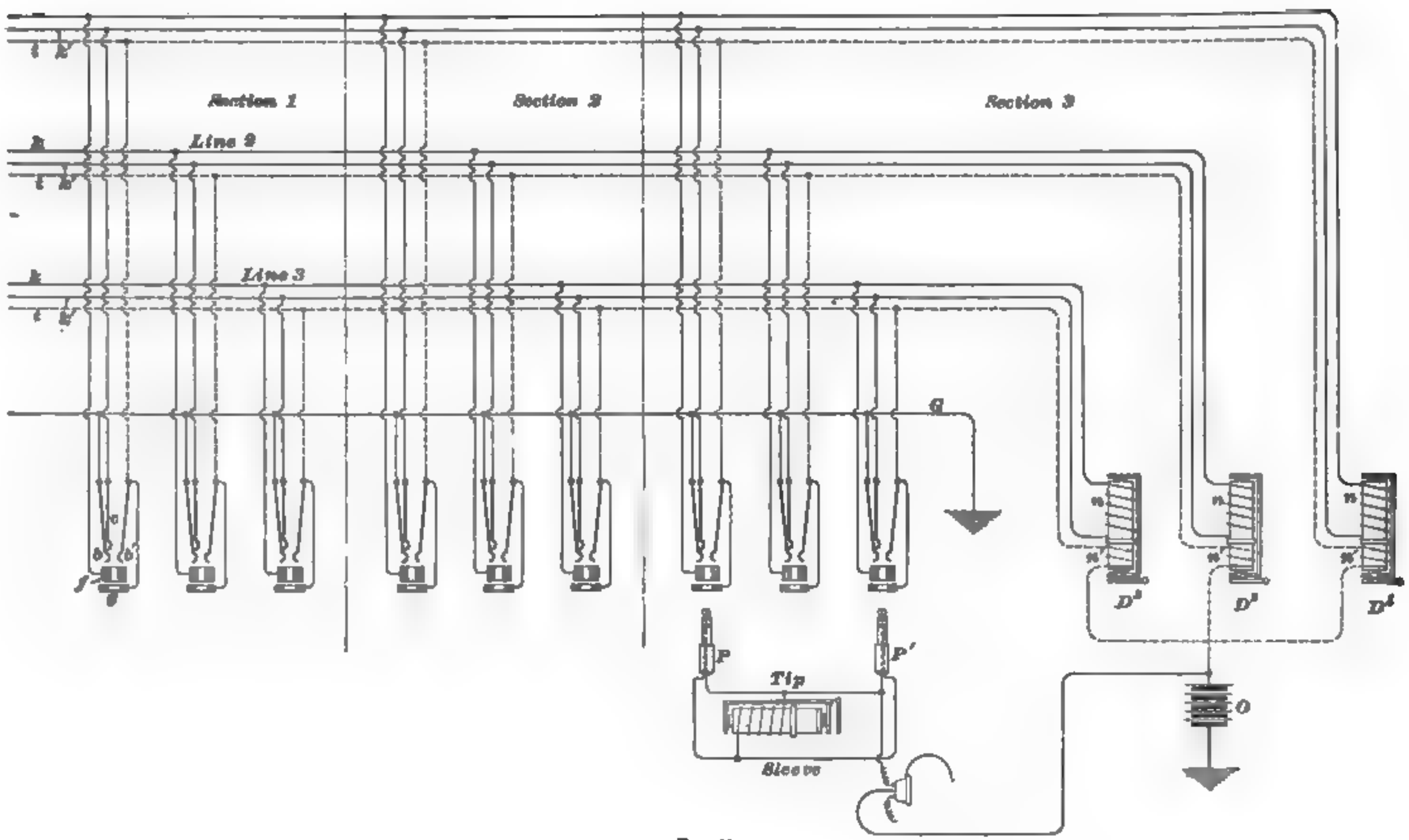

Section 1
Section 2
Section 3
Line 2
Line 3
Tip
Sleeve
G
P
P'
D²
D³
D⁴
O

FIG. 18

THE BRANCH-TERMINAL MULTIPLE BOARD

38. Line Circuits.—The **Branch-terminal multiple switchboard** was designed to overcome the objections to the series-multiple board, and, it may be said, has to a large extent done so. This type of switchboard has, in turn, been superseded by or converted into central-energy multiple switchboards. The general arrangement of spring jacks and drops at the various sections of the board is shown in Fig. 18, where three lines pass successively through three sections of the board, each being connected with a jack on each section and also with a drop on one of the sections. Each jack is composed of five parts: a test thimble *g*, a sleeve thimble *f* immediately behind it, a tip spring *c*, and two signal-restoring springs *b*, *b'*. The test thimble *g* is permanently connected to the spring *b'*, the two being connected by a

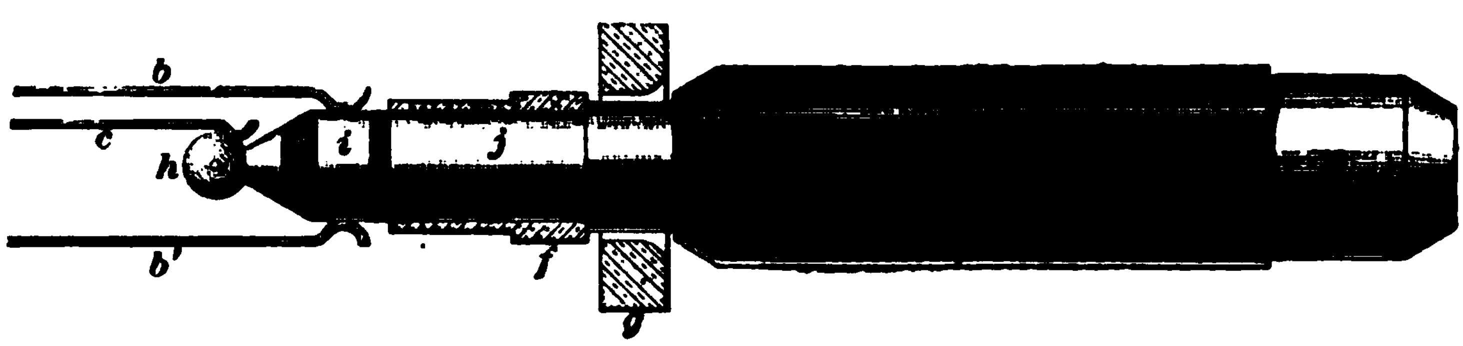


FIG. 19

branch wire with the test wire *t*, one of which is provided for every line in the exchange. Each test wire leads through a restoring coil *n'* of the drop of its line, and then passes to ground through a common battery *O*. The sleeve thimble *f* is connected by a branch wire with the sleeve side *k* of the line, and the tip spring *c* is similarly connected to the tip side *k'* of the line. The line coil *n* of each drop is permanently bridged across the two sides *k*, *k'* of its line, and is therefore made of high resistance and impedance. These drops are of the electrically restoring type made by the Western Electric Company. The spring *b* at each jack is connected with the ground through a heavy wire *G*. The arrangement of the contacts in the spring jack and of the contacts of the plug is shown in Fig. 19, in which *h* is the tip of the plug and *j* the sleeve adapted to make contact, respectively,

with the tip spring c and the sleeve thimble f. These, h and j, are connected with the tip and sleeve strands of the cord circuit in the ordinary manner. A separate contact ring i is provided on each plug, which is entirely insulated from all other parts of the plug, and which is adapted to make contact with, and thus connect together, the two signal-restoring springs b, b' in each jack. The cord circuit is shown in greatly simplified form in Fig. 18, a clearing-out drop being connected in a bridge circuit across the tip and sleeve sides of the cords, and half of an operator's head-receiver circuit being connected between the tip side of the cord circuit and that pole of the battery O which is not grounded. The operator's telephone is arranged to be bridged across the cord circuit by means of a key, but it is shown connected, as in Fig. 18, for the purpose of simplifying the explanation of the busy-test circuit.

OPERATION

39. If the subscriber on line *1* desires a connection, the drop D^1, the coil n of which is connected across his line, is thrown in the ordinary way. The operator at that section of the board then inserts the answering plug P into the jack of that line. This connects the tip and sleeve sides of the cord circuit with the tip and sleeve sides of the line, respectively, and the operator is, by means of her listening key, enabled to bridge her talking set across the cord circuit and communicate with the subscriber.

40. Test.—The insertion of the plug into the jack, besides connecting the cord circuit with the line circuit, brings about two other useful conditions. It grounds the test wire t belonging to line *1*, and therefore each of the test thimbles g of all the jacks on that line. This grounding is accomplished by the connection of the springs b, b' through the ring i of the plug; the circuit from any test thimble on that line to ground being traced from the thimble g to the test wire t, thence to the spring b' at the section where the plug is inserted through the ring i on the plug to spring b, which is grounded through the wire G. The connection of

all the test thimbles to ground, as long as a plug is inserted in any jack of the line, is for the purpose of producing a distinguishing condition on that line to enable an operator at another section to determine whether or not that line is busy.

If, while the test thimbles of a line are so grounded, an operator at another board applies the tip *h* of one of her plugs to the thimble *g* of that line at her section, a click will be produced in her receiver, due to a flow of current from the battery *O*. The circuit through which this flow takes place may be traced from the positive pole of the battery *O* through one-half the winding of operator's receiver–tip *h* of the plug used in testing–test thimble *g*–ground, as already explained, and back to the negative pole of the test battery, which is itself grounded. It is obvious that, if the test thimble *g* of a line is not connected with the ground, no current will flow through the receiver and no click will be produced.

41. Restoring Drops.—The other condition brought about by the insertion of the plug into the jack is the establishment of a circuit containing the restoring coil *n'* of the annunciator and the battery *O*. This circuit may be traced from the positive pole of the battery through restoring coil *n'*–test wire *t*–spring *b'*–contact ring *i* on plug–spring *b*–ground wire *G*–ground to negative pole of battery *O*. The current flowing through this circuit energizes the restoring magnet, and restores the shutter to its normal position.

42. Complete Circuits.—The circuits of this system are shown more in detail in Fig. 20. The various parts in this figure bear the same reference letters as those used in Fig. 18, and although the diagram is arranged in an entirely different manner, the line circuits connecting the subscriber's station with the spring jacks and annunciators at the central office are identical with those in that figure. Two pair of plugs and their accessory apparatus are shown in connection with Fig. 20, one pair being located at section *1* and the other at section *2* of the switchboard. It must be remembered that the two spring jacks shown in proximity to the upper pair of plugs *P* and *P'* are at section *1*, and those in

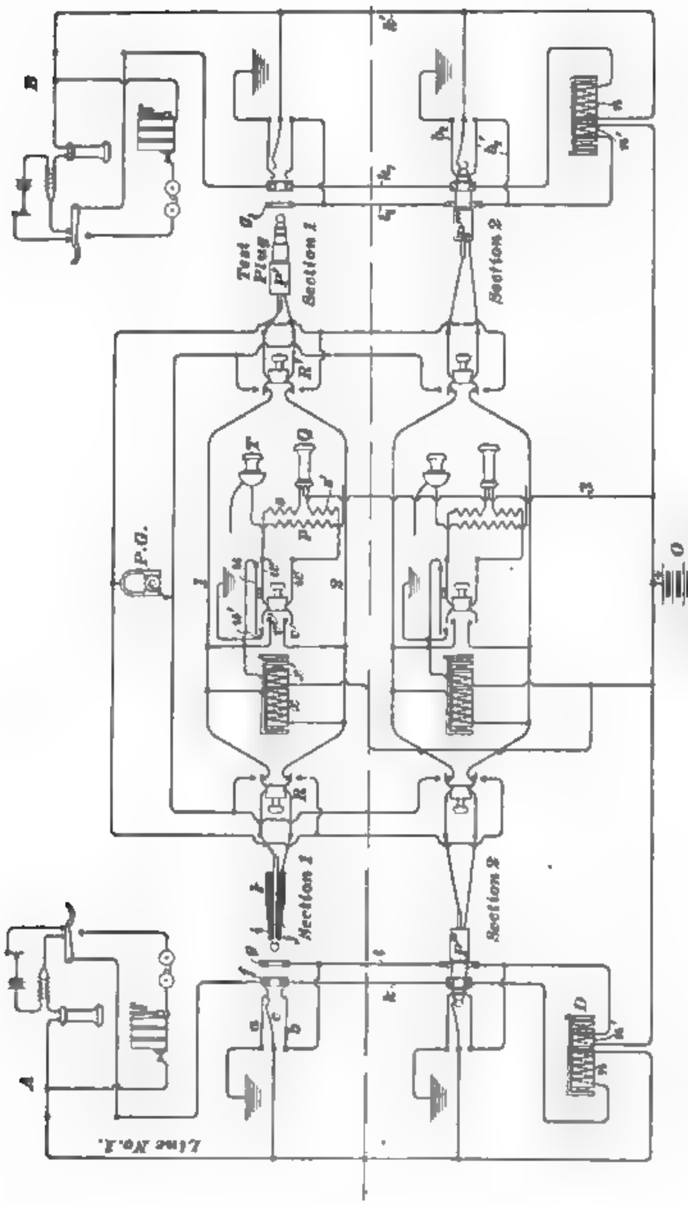


Fig. 20

proximity to the lower pair of plugs P'' and P''' are at section *2*. R and R' are two ringing keys, adapted, when depressed, to connect the circuit of the power generator *P. G.* across the terminals of the corresponding plug, at the same time cutting off the remainder of the cord circuit. Normally, however, when these keys are not depressed, the two sides of the cord circuit are continuous, the tip of the plug P being connected to the tip of the plug P' by the conductor *1* of the cord circuit, the connection between the sleeve contacts on the plug being made through conductor *2*. Across the tip and sleeve strands of each cord circuit is bridged the actuating coil x of the clearing-out drop, this coil of course being wound to a high resistance and impedance, in order to prevent the passage of the voice currents from one side of the cord circuit to the other.

43. In Fig. 18, the tip side of the cord circuit was shown grounded through half of the operator's telephone receiver, to aid in explaining the test circuit. It is necessary for the purpose of testing that the coil of the operator's receiver should be permanently grounded through the test battery; and in order that this shall not affect the balance of the line, as it would do if the ground connection were made at the end of the receiver coil, it is made instead at the center of the coil, and the secondary winding of the operator's induction coil is divided, one-half being connected in the circuit on each side of the receiver coil. This is indicated in Fig. 20, where Q is the operator's receiver and s and s' the two halves of the secondary coil connected on each side of the receiver coil. The terminals of the secondary circuit are connected with the two springs w, w' of the listening key, which springs, when the key is closed, make contact with the anvils v, v', thus bridging the operator's secondary circuit across the cord circuit. The primary winding p of the induction coil is connected with a transmitter T in a local circuit containing a battery, but not shown in the figure, and acts inductively on the two halves of the secondary winding s, s' in exactly the same manner as if they were not divided. In connection

with the listening key is the auxiliary spring u, connected with one terminal of the restoring coil x' of the clearing-out drop of that cord circuit. The other terminal of the coil x' is connected with the positive pole of the battery O. This spring makes contact with the grounded anvil u' when the listening key is closed, and thus serves to excite the restoring coil x' when the operator listens in. Two metallic-circuit lines, leading from the subscribers' stations A, B, are shown connected by the pair of plugs P'', P''' at section *2* of the board. The operations by which this connection was brought about may be understood from the description given in connection with Fig. 18.

44. We will assume now that the operator at section *1* (see Fig. 20) has inserted her answering plug P into the jack of some third subscriber, whose line is not shown, and that that subscriber desires a connection with subscriber B, whose line is already busy by virtue of the connection at section *2*. The operator at section *1*, however, does not know that this line is busy, and in order to ascertain its condition, she applies the tip of the plug P' to the test thimble g, of the jack on that line, while her listening key is in its closed position. Current from the positive pole of the battery O will then flow through the wire *3* and through one-half of the coil of the operator's receiver Q and one half s of her secondary coil to the spring w' and anvil v', which is in connection with the tip strand *1* of the cord circuit. From the tip of the plug P' the current then passes to thimble g, of the jack at section *1*, and by test wire t, to the spring h', at the plugged jack at section *2*; here it passes through the auxiliary ring of the plug to spring h, and to ground, and thence to the negative pole of the grounded battery O. The click produced in the operator's telephone by this flow of current will inform her that the line is busy, and she will at once notify the calling subscriber to that effect.

45. Simplified Test Circuits.—The test circuit is shown, stripped of all detail, in Fig. 21, in which g, is the test thimble at section *1*, and g' the test thimble on the same

line at section *2*. The dotted line shown in connection with the thimble g' represents the ground connection that may exist by virtue of a plug being inserted into that jack, as already shown. If this ground connection does not exist, the test thimbles and the test wire t_1 will be raised to the same potential above the earth as the tip of the testing plug *P*, this potential being due to the battery *O*, and therefore no current will flow through the operator's receiver coil when the plug tip is applied to the thimble g_1. If, however, the ground connection at g' does exist, the potential of the test wire and test thimble will be the same as that of the earth, and current from the battery will flow through a divided path to the ground, one branch of which will include the restoring coil n' of the line annunciator, and the other of which will include one-half of the operator's receiver coil and of her induction coil, as traced out in the preceding article.

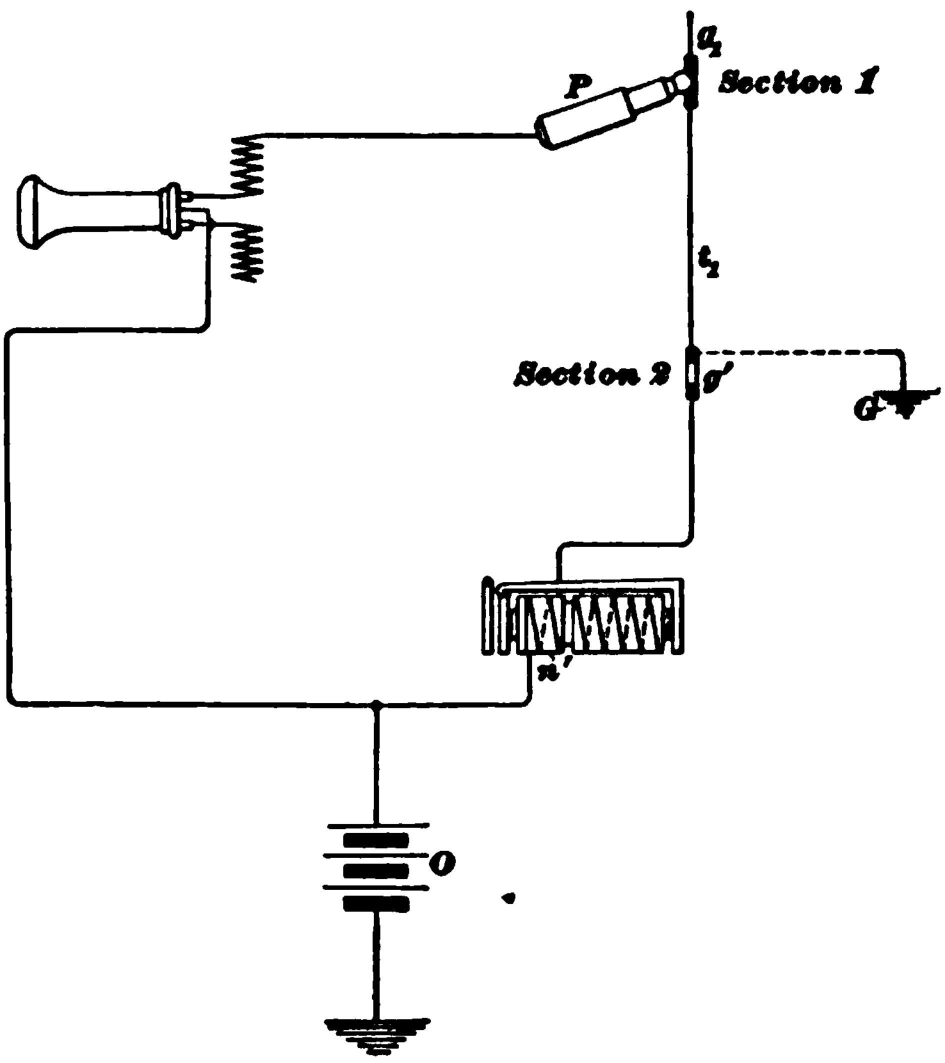


Fig. 21

46. A study of the diagrams of this system, especially of that shown in Fig. 20, will show that, with one exception, no part of the actual talking circuit established between two subscribers is at any time grounded by the operations of testing or of restoring the various shutters. The exception mentioned is due to the ground connection from the center point of the operator's talking circuit, which is connected with the line when the operator listens in. Inasmuch, however, as an equal amount of resistance and impedance is

placed on each side of this ground connection, the balance of the circuit is in no wise destroyed. In order to prevent the grounding of one side of the line circuit when a plug is inserted into a jack, the thimble *g* is made sufficiently large to clear the sleeve of the plug when inserted; this is shown in Fig. 19.

47. Advantages of Branch-Terminal System.—The branch terminal system, as described, represents the highest development of the multiple switchboard, prior to the extensive use of lamp signals and centralized transmitter batteries. A complete multiple-board system, embodying these latter features, will be described when the lamp signals and centralized-battery arrangements are discussed. It is not difficult to see the advantages of the branch-terminal system over the series-system. Among them may be mentioned the following: (1) The continuity of the line circuit is not dependent on any of the jack-contacts, and, in fact, no broken contacts exist in the jacks. (2) The balance of the line is not destroyed by grounding one side of the cord circuit, as in the series-system. (3) The use of self-restoring switchboard drops is rendered an easy matter; and, lastly, (4) the two branches of the metallic circuit of a line, which run through the entire length of the board, are always of the same length, and therefore possess the same electrostatic capacity. This latter fact is not true of the series-multiple board, because, on the insertion of a plug into the jack, one branch of the line circuit is cut off at the jack, thus leaving an open branch connected with one side of the line. This open branch extends through the switchboard cables and frequently produces cross-talk by receiving an inductive charge from a similar open branch of another line. Since the two line wires from one subscriber run together throughout the exchange, they can be twisted together, thus avioding all cross-talk and disturbances due to induction from neighboring wires.

MULTIPLE-SWITCHBOARD JACKS AND PLUGS

48. Multiple Jacks.—Reference to the diagrams in Figs. 18 and 20 will show that each spring jack comprises five separate contacts, formed by three flexible springs and two stationary sleeves or thimbles. The construction of such a jack would be indeed a simple matter were it not for the fact that space must be economized to the last degree. This is rendered necessary by the requirement that each operator shall have within her reach a jack for every line in the exchange, and therefore if, as in some of the very large exchanges, the number of lines centering at one central office is 6,000, it is necessary that within the reach of every operator shall be provided that number of jacks.

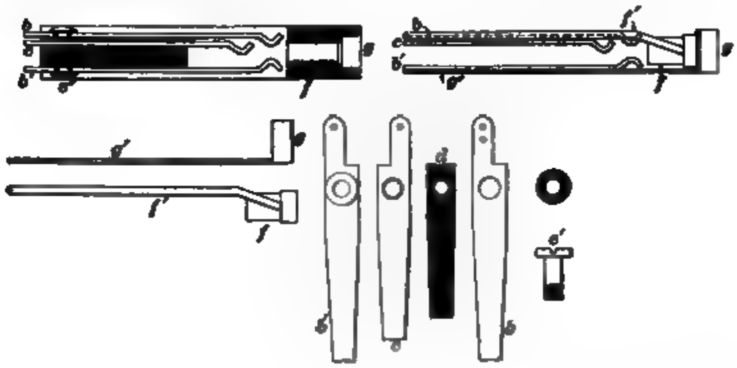


FIG. 22

The jacks must, therefore, be of such size and so arranged that all of them may be placed in the smallest space possible, both as to width and height. In order to obtain such results, the jacks are usually arranged in strips of twenty or more, the strip being as narrow as permissible and the jacks as close together as their size will allow. A great deal depends on the arrangement and number of springs whether a jack can be made on close centers. Until recently, there was no boards made with jacks closer than ½ inch; this would permit of a switchboard with a capacity of 6,000 lines. Improvement in apparatus and the demands of larger exchanges have

reduced the spacing to $\frac{7}{16}$, $\frac{3}{8}$, and, finally, to $\frac{5}{16}$ inch. With the last size, there are but two contacts to the jack. It looks now as though the size would reach $\frac{1}{4}$ inch. It is not so difficult to make the jack on small centers, but where exceedingly large boards demand the small jacks, the cables connecting them become excessively cumbersome and hard to handle. Moreover, it is also very difficult to make the small plugs strong enough to stand the work, for the plug handles must be a trifle less in diameter than the spacing of the jacks.

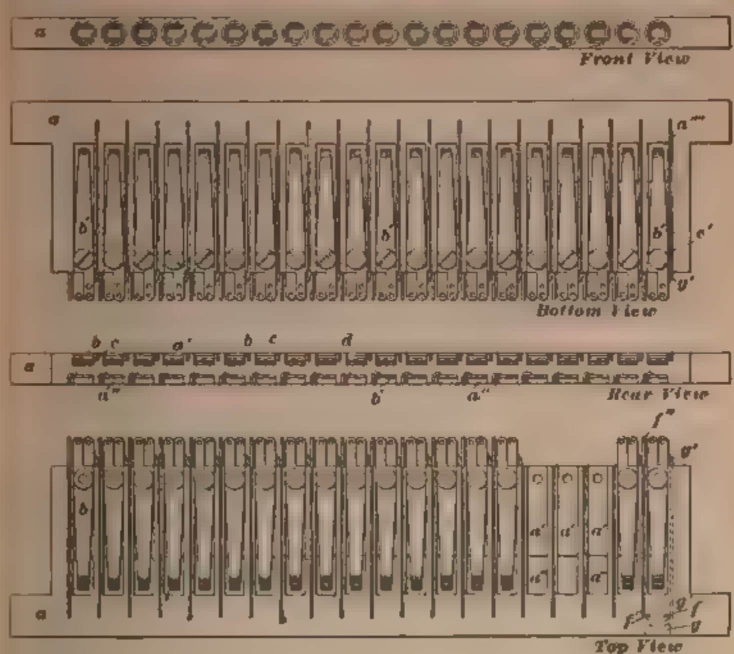


Fig. 23

49. The parts that go to make up a single jack used in the branch-terminal multiple switchboards are shown in Fig. 22, and a whole row of them in Fig. 23, in which *a* is a strip of hard rubber, properly grooved and bored to receive the contact springs *b*, *b'*, and *c* and the thimbles *f* and *g*. The hard-rubber strip *a* is of the shape shown in Fig. 23, and is of such length as to accommodate twenty jacks mounted

on it side by side. Each strip of twenty jacks is mounted horizontally in the switchboard, being secured to the frame of the board by the lugs at the ends of the strip. In the upper side of the strip are milled transverse grooves a' for accommodating the springs b and c, and in the under side of each strip are milled similar grooves a'', in which lie the springs b'. The grooves a' and a'' extend from the rear of the strip to within about $\frac{3}{4}$ inch of the front of the strip. At this point they are united by a rectangular opening a'''. In the bottom of the groove a' is placed the tip spring c. Directly over this is laid an insulating strip d, shown in the details in Fig. 23. Over this strip is laid the spring b, its mate b' being placed in the groove a'' on the opposite side of the strip. All these springs are secured in place by means of a small bolt e' passing through all the springs and the insulation. The springs, however, are carefully

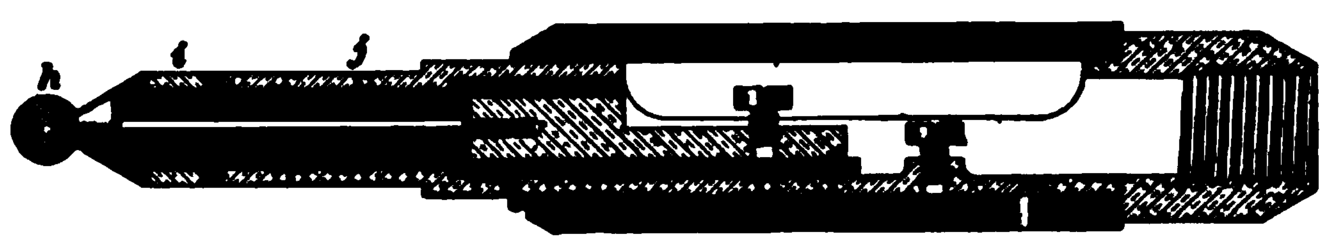


FIG. 24

insulated from the bolt by means of a hard-rubber bushing. The holes drilled from the front edge of the jack-strip to the rectangular opening connecting the two slots are of greater diameter at the front of the strip than at the rear, for the accommodation of the thimbles f and g. The thimble f is provided with a rearwardly extending strip f', which extends through an oblique hole f'' to the upper side of the jack-strip, where it follows a saw slot to the rear of the strip, as shown in the top view of the jack-strip in Fig. 23. In a similar manner, the thimble g is provided with a rearwardly extending strip g', which passes through the saw slot a'''' on the under side of the jack-strip to the rear of the strip. The strip g' is then soldered to the spring b', thus permanently connecting the test thimble g with that spring. The test thimble g is made of larger internal diameter than the line thimble f, in order that the plug when inserted in the jack may make

contact with the line thimble only, thus keeping the test circuits entirely free from the line circuits.

50. In Fig. 24 is shown a sectional view of a plug used with the jack described in the branch-terminal system. The cord connectors are shown within the cavity in the handle of the plug, one of them being in metallic connection with the tip *h* of the plug, and the other with the sleeve *j*. The contact ring *i* on the plug is entirely insulated from all other parts, and serves merely to short-circuit the springs *b* and *b'* when inserted in the jack.

DIVIDED-MULTIPLE SWITCHBOARDS

51. About 1897, Mr. M. G. Kellogg devised what is known as the **divided-multiple switchboard** for a magneto-, or local-battery, system. It was said that this type of switchboard would render possible the construction of very large exchanges consisting of single offices, thereby reducing the initial cost of equipment and maintenance. The reduction in the cost of equipment would be due to the reduction of the number of multiple jacks that would be required. Four-division multiple switchboards were installed in St. Louis and Cleveland, the one in St. Louis being replaced about 1905, and the one in Cleveland about 1904, by a modern central-energy multiple switchboard. Each divided-multiple exchange consisted of four rows of sections, each row containing one line signal and one answering jack associated with each line, and multiple jacks of each line in one row only, that is, only one-fourth of the lines had multiple jacks in a given row. The four rows may be designated as the *A*, *B*, *C*, and *D* divisions. The line signals, which were very small and compact, consisted of small polarized drops, which would be operated by a current in one direction only, mounted in strips of twenty on $\frac{3}{4}$-inch centers. Two of the drops on each line were oppositely polarized and bridged across the two line wires, while the other two, also oppositely polarized, were bridged from one side of the line to ground.

The signaling apparatus at each subscriber's station consisted of a source of current and four keys (push buttons), so arranged that current could be sent in either direction through the two wires, which constituted a complete metallic circuit, or in either direction through one side of the line with the ground as a return, by pressing the proper key. At St. Louis in 1904, the hand generator was so arranged as to give positive and negative pulsating currents, and by pressing one of the four selective keys, the drop at any one of the four divisions was operated in very much the same manner as the biased ringers in a selective four-party line system. Each subscriber was designated by a letter as well as by a number. For example, line 1343A had multiple jacks in the A division of the board, while 1343B, 1343C, and 1343D had jacks in the B, C, and D divisions, respectively. Although it must be admitted that this system is very ingenious, the fact that the subscriber had to select one of four buttons each time a call was made, and the complication of both the subscriber and switchboard circuits proved a serious disadvantage. Moreover, the cost of outside construction and maintenance is much less when each division, which then becomes a separate exchange, is located near the center of its own group of subscribers, with trunks between the various exchanges. It is doubtful if any more divided-multiple switchboards will be installed in the near future in the United States, for which reason it does not seem advisable to devote any more attention here to this type of switchboard. A Mr. W. Aitken, of England, devised a very complete four-division multiple switchboard arranged on a common-battery system, but up to 1906 such a system had never been built.*

*Descriptions of the St. Louis and Cleveland divided-multiple switchboards were given in Sound Waves for June, 1904, and a description of a two-division (20,000 lines each) common-battery system, devised (patents Nos. 759,641 and 759,762) by E. H. Smythe, and proposed for use in St. Petersburg by the Western Electric Company, is given in Sound Waves for July and August, 1904, and in the Western Electrician for June 18, 1904. The system described by Mr. Aitken was printed in Telephony for August, 1903.

SWITCHBOARD TROUBLES

52. Drops.—One of the most frequent causes of trouble in switchboards is poor adjustment of the drops. To tell in detail, however, just how to adjust them would be a rather difficult thing to do, especially as there are so many kinds. The best way to get a thorough understanding of the mechanism of the drop is to practice on one not in use, before attempting to adjust one in service. The same advice applies to relays with the additional precaution that all contacts be kept clean and protected from dust. Careless inspectors frequently leave off the covers and wonder why it is they have so much relay trouble; try putting things back as they originally were, and the result will be surprising.

53. Spring Jacks.—Dust in these, which is a frequent cause of trouble (especially in series-multiple boards), may be dislodged by the use of a pair of bellows; this failing, a piece of No. 6 copper wire, flattened at the point, may be inserted into the jack and passed between the spring and the insulated point contacts. In testing for trouble in a series-multiple board, start at the first jack from the line end, insert an operator's calling plug in the jack and ring; if the drop falls, the trouble is between you and the test board, rack, or line terminal; repeat the same test at the test board with an instrument there; if the operator answers you, the trouble is outside of your office and may be in the leading-in wires, cables, line, or subscriber's instrument. If, however, on making the first test, the drop did not fall, repeat the test at the next jack; if now all right, the trouble is at or between these two jacks, and may be due to a broken wire or bad connection. In searching for trouble of this character, be very careful in handling switchboard cables; sometimes a great deal of trouble is caused by carelessness in handling them that is not discovered until later.

TELEPHONE-SWITCHBOARD APPARATUS

SIGNALING DEVICES

TARGET SIGNALS

1. A target is a switchboard annunciator, or signal, whose shutter rises or falls as the armature is attracted and then returns, by its own weight, to its normal position when sufficient current ceases to flow through the coil. Target signals are used for line and supervisory signals mostly in connection with small central-energy and common-battery supervisory systems.

NORTH TARGET SIGNAL

2. The target signal made by the North Electric Company and used in the same company's common-battery signaling system is shown in Fig. 1. It consists of a rectangular iron

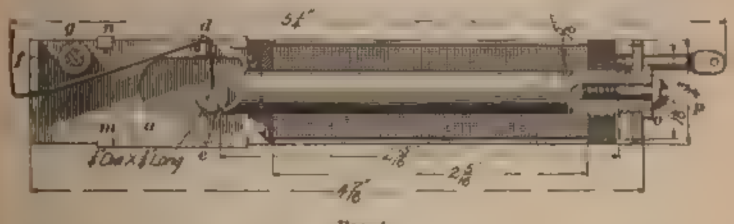


FIG. 1

frame *a* made from a single piece of soft sheet iron about $\frac{3}{4}$ inch wide, $\frac{1}{16}$ inch thick, and 11 inches long, the two ends of which do not come quite together in front, where each end

is provided with a screw hole for fastening a white, or bright, number plate. There is also a brass rod *g* that firmly holds the two sides of the iron frame a certain distance apart. In the rear of the frame is a threaded hole in which the iron sleeve *o* may be screwed. An iron screw *p* passes through a hole in the sleeve *o* and screws into the iron core. By setting the sleeve *o* in any position desired and screwing *p* up tight, the core is drawn tight against the sleeve *o*, thereby providing a means for adjusting the iron core forwards or backwards, locking it and also preserving a path of iron for the lines of force between the core and iron frame. The forward end of the core and coil are held in position by two rivets projecting from the iron frame into notches in the hard-rubber front head of the coil. To remove the core and coil, it is merely necessary to remove the screw *p*, slip the rear end of the core and coil up free of the frame, and pull it backwards.

The iron core has a length of about $2\frac{11}{16}$ inches and a diameter of $\frac{5}{16}$ inch. The outside diameter of the coil is about $\frac{11}{16}$ inch, which gives a winding depth of about $\frac{3}{16}$ inch; the length of the winding space is $2\frac{5}{16}$ inches. This space is filled with No. 38 B. & S. bare copper wire, adjacent turns being separated by green silk thread and the layers by paper. The resistance is about 400 ohms.

A small portion of each side of the iron frame, where the ends of the cylindrical armature *c* move, is cut out, but thin pieces *m*, *n* of sheet iron, placed on the outside, cover these holes in the frame. The lines of force coming out of the core divide and pass each way through the armature to the sides of the iron frame. The front end of the core and the holes in the sides of the iron frame are so shaped that the air gaps between the core and armature and between the armature and frame at each end decrease in length as the armature moves about its point of suspension toward the core; hence, the armature will move toward the core when it is magnetized by the coil.

The armature *c* is a cylindrical piece of soft iron about $\frac{3}{4}$ inch long, $\frac{1}{4}$ inch in diameter; in one slot is rigidly clamped

the rear end of the aluminum target *t* and a stouter piece of brass, by means of which the armature and target are hung on the horizontal brass pivot rod *d*. In another slot is clamped a small piece of brass *c*, which projects nearly $\frac{1}{64}$ inch beyond the cylindrical surface of the iron armature and limits the motion of the armature by coming into contact with the iron core or the edge of the holes cut in each side of the frame when the armature is attracted. This prevents the sticking of the armature due to residual magnetism.

3. As the armature approaches the core, the target *t* moves downwards and exposes a white, or bright, surface behind it. The front of the target and all parts normally in view are painted black. The rear surface of the target is bright and probably tends to reflect light from the top of the switchboard on to the white surface, which is exposed to the operator when the target is in its lowest position. When current ceases to flow through the coil, the armature is no longer attracted toward the core and its weight causes the target to rise and hide the previously exposed bright surface. The terminals of the coil are soldered to stout brass terminal rods that project through two slots formed in the rear of the iron frame. The pole piece, armature, and the iron screws *o*, *p* are plated with copper to prevent rusting. A piece of cotton is glued to the target arm, where it strikes against the iron frame, to reduce the noise.

These target signals are self-contained and mounted in strips of ten, so that any individual signal, or a complete strip, may be removed without interfering with other apparatus.

DEAN TARGET SIGNAL

4. The **Dean target signal**, designed for the Western Electric Company, is somewhat similar to the North target signal, but has the aluminum target bulged out in spherical shape in order that the operator may see it more readily from any direction. Instead of the pole piece being curved, the armature is eccentrically curved, so that as it turns

the attraction increases because it approaches the iron core. Provision is also made for closing a night-alarm circuit when the signal is operated.

GRIDIRON SIGNAL

5. In Fig. 2 is shown a target signal called a **gridiron signal,** from the resemblance of the target, when exposed, to a gridiron or grating. The figure shows a rear and a front view of two target signals, a sectional view through the center of one signal, and a view of the armature support

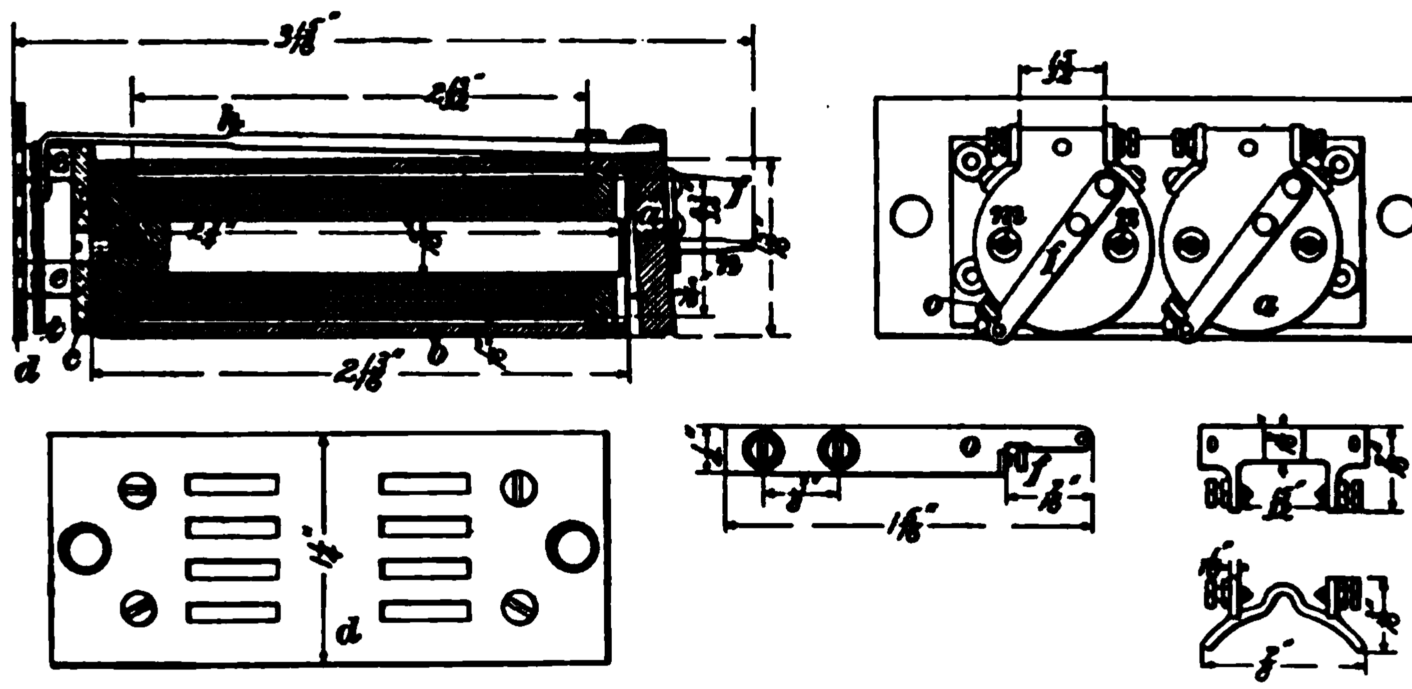


FIG. 2

and night-alarm springs that are stamped out of $\frac{1}{16}$-inch sheet brass, the contacts being platinum rivets. This type of signal is extensively used on long-distance, toll, common-battery signaling, and small central-energy systems. This particular signal is made by the Kellogg Switchboard and Supply Company, and in general construction resembles the Warner tubular drop.

6. The shell *b* is drawn from one piece of soft iron or mild steel and, together with the armature *a*, is heavily plated with copper to prevent rusting. The core and shell are secured to a brass mounting plate *c* by screws. The brass front plate *d* is also fastened with screws to brass posts *e, e* riveted to the mounting plate *c*, a $\frac{1}{4}$-inch space being left between plates *c, d* in which the target *t* hangs. The target, which is made of a flat piece of sheet aluminum

1 inch long by $\frac{17}{32}$ inch wide, is riveted to the rod *h*, which is firmly fastened to the armature *a*. The front plate *d*, the front of which is painted black, has four horizontal slots, one above the other, for each signal, each slot measuring $\frac{7}{64}$ inch high by $\frac{1}{2}$ inch long, and separated by bars $\frac{1}{64}$ inch high. The aluminum target has black bars painted across it horizontally, in such a position that only black appears through the slots in the front plate when the armature rests in its normal position. But when the armature *a* is held in its attracted position by a direct current through the coil, it raises the aluminum target *t* so that the bright aluminum appears through the slots in the front plates as four bright bands, giving a signal that is very easily seen by the operator. When the current ceases, the weight of the target, supporting rod, and armature causes the target to fall into its normal position, showing only black through the slots in the front plate.

The coil is usually wound to a resistance of about 500 ohms with about No. 38 B. & S. silk-covered copper wire. The length of the winding space is $2\frac{13}{32}$ inches and the depth about $\frac{3}{16}$ inch. The coil is covered with two thicknesses of paraffined paper. The terminals of the coil are soldered to two stout, tinned-brass wires *m*, *n* fixed firmly in the rear head of the coil and projecting through two holes $\frac{3}{16}$ inch in diameter in the iron armature. The outside ends of these terminals are flattened and provided with a hole in which the end of a switchboard wire may be readily inserted and soldered. Many switchboard devices are now provided with terminals of this character.

7. To the rear surface of the armature is riveted a flat German-silver spring *l* provided at the end that projects beyond the armature with a platinum rivet. This platinum rivet makes contact, when the armature is attracted, with a flattened platinum rivet in a brass piece *o* secured to the iron shell, by two screws, but insulated from it. This brass piece projects toward the rear, its end being tinned and provided with a hole, thus forming a terminal. This pair of contacts may be used in a night-alarm circuit.

TWO-COIL TARGET SIGNAL

8. Fig. 3 shows a **two-coil target signal** used by some Bell Companies. It has two cores and two coils, a heavy iron armature *a*, and an aluminum shutter. The iron framework of the switchboard to which the signal is fastened by screws *c*, *d* forms the yoke for the iron cores. The armature and shutter are shown in their attracted position; the armature is so pivoted that its weight, together with that of the aluminum target *t*, causes the latter to move down out of sight when the armature is not attracted by the two cores. This signal is frequently wound to have a resistance of about 45 ohms. *m*, *n* is a black painted strip on the face of the target; it can be seen through a slot in the front of the switchboard in the normal position of the target.

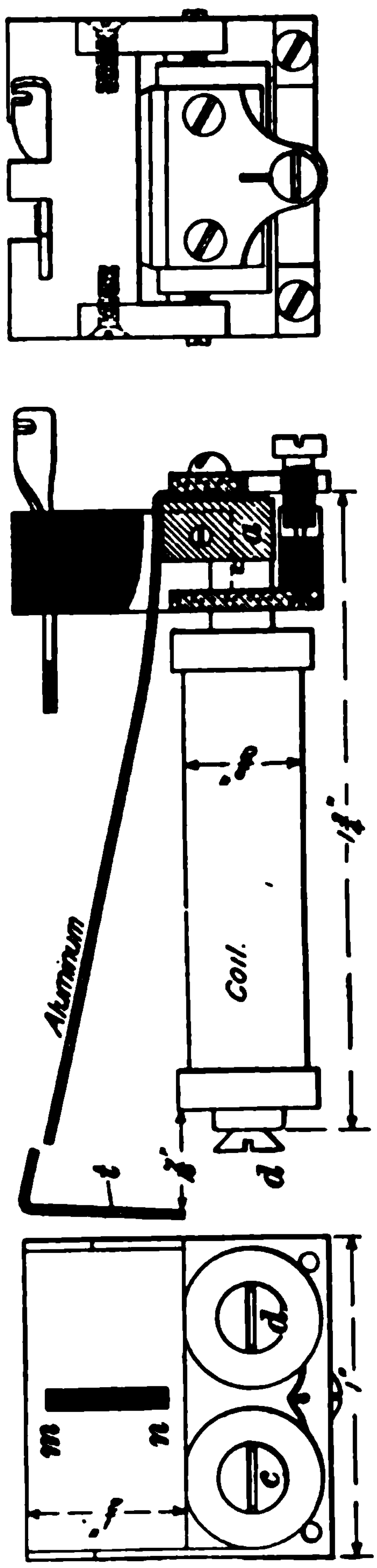


Fig. 3

RELAYS

9. **Relays** are now very extensively used in telephone systems, especially in common-battery signaling and central-energy systems. Their design and construction varies a great deal, depending on the purpose for which they are used. Where many of them must be mounted near one another, they must be made no larger than is really necessary in order not to occupy too much space; they must have a good iron circuit to be efficient; and practically covered with a case of almost any metal where they are placed very close together, in order to prevent cross-talk. Cross-talk is usually eliminated by enclosing

the relay in a metal shell or case, due to the metal case acting as a short-circuited, or low-resistance, winding. Should there be any tendency for lines of force to stray from the prescribed iron path, they will cut the metal case, as they are set up or die out, and generate currents in it, but having thus expended their energy they will manifest no tendency to spread any farther. Hence, the return circuit may be made of iron and good enough to be efficient; and then if this is not sufficient to eliminate cross-talk, the relay may be enclosed in a case made of almost any metal. It is also necessary to keep as much dust as possible out of the relay to prevent bad and dirty contacts. For these reasons, most relays are enclosed in cylindrical or other shaped cases of iron, brass, or aluminum. All relay contacts should be made of platinum rivets to reduce, as much as possible, the corrosion due to moisture, dust, or sparkling. Copper rivets in the armature or other means are usually provided in all relays to prevent the touching and sticking of the armature to the core due to residual magnetism after the current ceases to flow through the coil.

PONY TELEGRAPH RELAY

10. In Fig. 4 is shown a **pony relay**, which is somewhat smaller than a regular telegraph relay. Pony relays are used

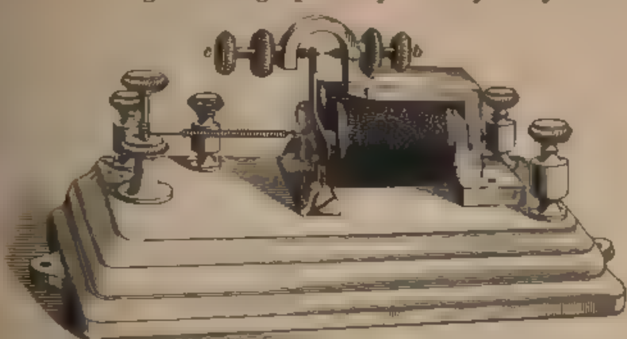


FIG. 4

in telephone systems where only one or two are required for a whole exchange, and when it would not, therefore, pay to

manufacture a special relay for the purpose. The full-sized regular telegraph relays are practically never used except in the telegraph side of circuits used for both telegraphy and telephony. A telegraph relay has two cores, two coils connected in series, an iron yoke, and an iron armature. The contacts are made of platinum. An adjustable retractile spring is used to draw the armature back to its normal position when the current ceases to flow through the coils. This relay occupies too much room for most telephone circuits and is not covered with a metal case. It is occasionally used as a pilot or night-bell relay and for testing circuits where so few are required that it would not be profitable to make a special relay for the purpose.

METAL-CASE RELAYS

11. Warner Relay.—A relay used somewhat by the Bell Companies, resembling in construction the Warner tubular drop and probably made from discarded Warner drops, is shown in Fig. 5. The iron armature *a* is pivoted in a brass

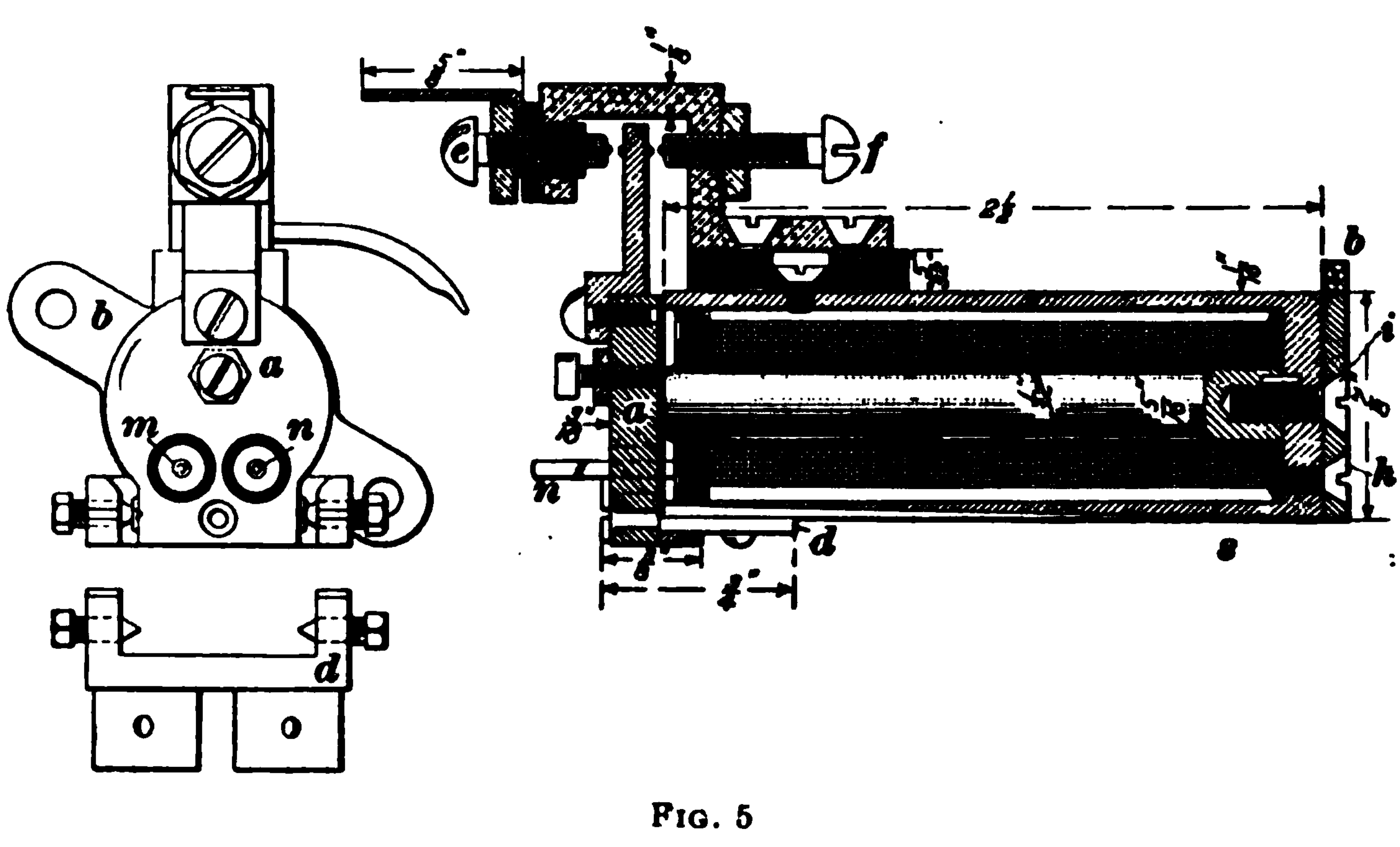


FIG. 5

stamping *d* that is held by screws to the outside of the iron shell *s*. This relay may be used to close a circuit through screw *e* in its normal or through screw *f* in its attracted position. The coil terminals *m*, *n*, are brought out, by means

of stout brass wires, through sufficiently large holes in the armature. The relay is mounted on a frame by means of a brass piece *b* that is secured to the relay by the screws *h*, *i*; the latter screw also holds the core and shell together. This relay is frequently wound to 500 ohms.

12. Kellogg Iron-Clad Relay.—In Fig. 6 is shown a **Kellogg iron-clad relay.** The coil and iron core are held in the iron shell, which is made of one piece, by means of a nut and projecting brass screw *c*, by which it is also fastened to a frame. The terminals of the coil are brought out by means of the brass rods *b*, *e*, which are rigidly fastened to the coil and easily slide through holes in the iron shell without touching it. The iron armature *a* has a projection *d*. The

FIG. 6

weight of the piece *d*, downward tension of the springs *m*, *n*, and the way in which the armature is balanced on the front edge of the piece *o*, tend to hold the armature a slight distance from the core and shell. The screw *s* merely holds the armature from falling off when the relay is handled, and does not in any way bind it. When current flows through the coil, both the core and shell attract the armature, but even then a copper rivet or screw prevents it from touching either the core or shell. When the armature is not attracted, the springs *m*, *n* touch the lower contact springs; but when attracted, the projection *d* lifts the springs *m*, *n*, so that they part from the lower and touch the upper contacts. The piece *d* has a strip of insulating material on its upper surface so as not to connect *m* to *n* when it lifts them. As these relays are mounted close together and are connected across the circuit during a conversation, the iron shell is a very desirable feature.

This is a flexible type of relay because almost any combination of springs may be used, one, two, three, or four sets of springs, with either top or bottom, or both top and bottom contacts. An objection to the relay is the fact that the springs are not enclosed in the shell so as to be protected from dust and moisture. Such relays are usually mounted in large glass cases.

13. Kellogg Tubular Relay.—Another type of relay made by the Kellogg Switchboard and Supply Company is shown in Fig. 7. This flexible type of relay has a magnetic circuit consisting of a core *c*, yoke *y*, and a bent armature *a*, *a*. When the relay is energized, the armature merely tilts,

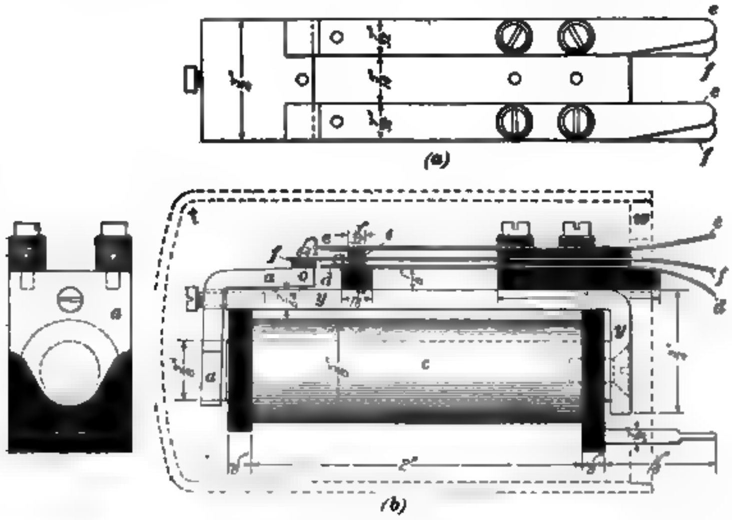


FIG. 7

thus raising the spring *f* into contact with *e*, contact with *d* being then broken. The tension of the spring *f* is downwards, the hole in it being large enough to permit it to move freely along the insulating piece *i*, whose function is to prevent a short circuit between *e* and *d*. To prevent the armature from sticking, due to residual magnetism, a brass or copper rivet is placed in the armature at *o* to prevent actual contact between the armature *a* and yoke piece *y*. To protect

the contacts from dust and also to prevent cross-talk between neighboring relays, the whole device is enclosed in a tubular case *t*, usually made of $\frac{1}{16}$-inch drawn iron, but sometimes of brass. This tubular shell *t* screws on a disk *w*. The shape of the front end of the armature *a* is shown in the front view. The principal dimensions are given on the figure. When this relay is used as a line cut-off relay in central-energy systems, there are two sets of springs mounted alongside of each other, as shown in the top view (*a*).

14. Bell Tubular Relay.—A similar flexible type of relay used by the Bell Companies for cut-off relays and other purposes is shown in Fig. 8. The only new feature is the

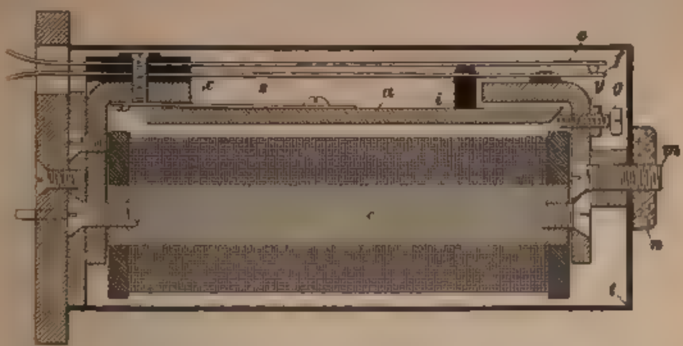


FIG. 8

use of two iron yoke pieces *x*, *y* fastened rigidly to the iron core *c* and an iron armature *a* supported from *x* by the flat spring *s*. The weight of the armature and downward tension of the contact spring *e* keep the armature against the screw *g*, by means of which the normal distance of the armature from the yoke *y* above it may be adjusted. When the relay is energized, the armature is drawn up by both yoke pieces *x*, *y*; the insulating piece *i*, which is thereby raised, moves easily through a sufficiently large hole in the spring *f* to raise the spring *e* without moving *f*. A sheet-iron shell *t*, which protects the whole relay from dust and eliminates cross-talk, is held in place by a screw *m* and a nut *n* that cannot be removed from the shell and lost.

15. Dean Enclosed Relays.—In Fig. 9 is shown one line and one line-cut-off relay made by the Dean Electric Company. The movable contact points are located at the extreme front of the relay, where they can be readily inspected, when the cover, which entirely encloses the working parts, is removed. The milled nut *n*, used to hold on the cover, cannot be removed from the cover and thus lost. The armature, which can be readily removed, rocks over two fixed points, one of which is shown at *c*. A neck on the brass spool projects just barely enough beyond the iron core to prevent the armature from touching it, thereby allowing the use of a very small air gap, which improves the efficiency of the relay. The coil terminals are so securely fastened that they cannot work loose or be pushed through so as to injure the windings. It is claimed that these relays are permanently and so well adjusted in the factory that subsequent adjustment is unnecessary. The springs are German silver with platinum contacts.

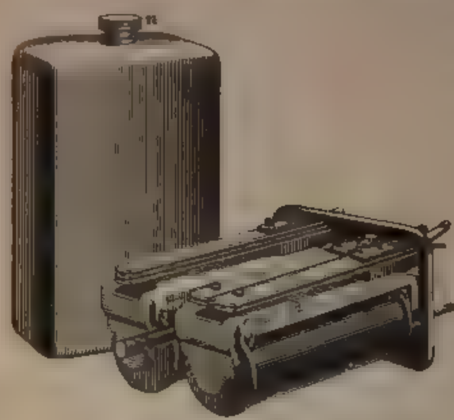


FIG. 9

16. Kellogg Cast-Iron Relay.—A type of relay made by the Kellogg Switchboard and Supply Company for use in lamp-signal magneto-switchboards is shown in Fig. 10. For a strip of ten relays, a single iron casting is drilled out for the reception of the relay coils and cores, sufficient space being left between the drillings to effectually prevent cross-talk. The construction is compact. The contact springs are thoroughly insulated both from the armature and the iron block containing the relays, and are made of German silver,

platinum-pointed. In the figure, one relay is taken apart and the armature *a* of another is removed to show the construction.

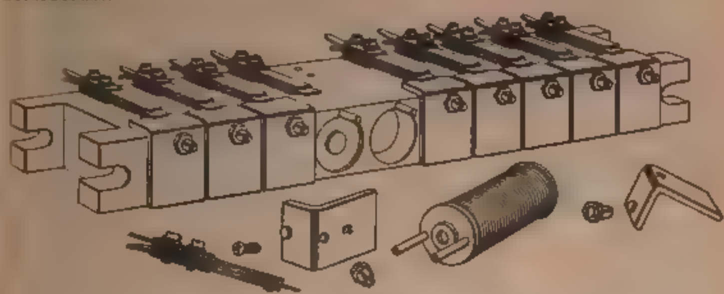


FIG. 10

17. Kellogg Supervisory Relay.—In Fig. 11 is shown an iron-clad relay used as a supervisory relay in some Kellogg central-energy systems. The coil and iron core in this relay are held in the iron shell by means of the projecting brass screw and nut *a*, and the whole relay is mounted

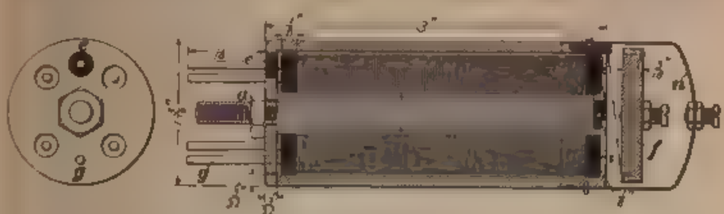


FIG. 11

on a frame by the same means. This relay has six terminals, because there are two coils requiring four terminals and a local circuit requiring two terminals. One of the latter *g* is connected to the iron shell and the other *e* to an insulated platinum-tipped contact at the center of the forward end of the core. The iron armature *f* is supported by a very thin piece of sheet copper *i* fastened at the lower end to the armature and at the upper end to the iron shell. Normally, the armature leans back against the brass cap *n*; but when the relay is energized, the whole armature is attracted and closes the local circuit. The sheet of copper has a small hole cut in the center through which the contact point

fastened to the iron armature projects slightly and touches an insulated contact in the end of the core when the armature is attracted. The copper strip also prevents the iron armature from touching the iron core or shell, even when attracted, and hence prevents the sticking of the armature to the core and shell when the current is interrupted; the weight of the armature is the only retractile force. The brass cap *n*, which may be readily removed by giving it a slight turn, protects the movable parts and contacts from dust.

18. Bell Iron-Clad Relay.—Fig. 12 shows a form of relay used by the Bell Companies for a number of years. This is of the tubular iron-clad form with a single contact at the end of the core. The armature *a* is a copper-plated iron disk that is so beveled as to give a knife edge to swing on and also to throw the weight back of the supporting point in order that it will fall back by its own weight when released. It is evident that this relay will operate properly only in a horizontal position. The copper plating on the armature is to prevent sticking. These relays gave trouble because of the uncertain contact between the edge of the armature and the cap *c*. To get around this difficulty a small spiral of wire *s* was connected to the armature and to the frame of the relay. This is a very sensitive piece of apparatus, but lacks the flexibility of some other types.

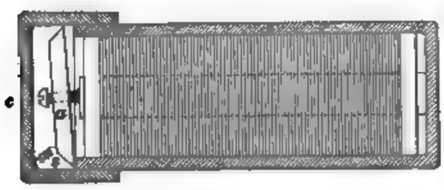


FIG. 12

19. Eureka Relay.—In Fig. 13 is shown a relay made by the Eureka Electric Company. All parts are accessible when the iron shell, which screws on the brass base *b*, is removed. The armature *a* is pivoted on a knife edge at *c* and is held by the spring conductor *s* at its normal position against the screw *e*, by means of which the distance between core and armature may be adjusted. This relay has platinum contacts and, as usually wound, is operated by .01 ampere.

20. The **Stromberg-Carlson enclosed relay** is shown in Fig. 14. Each coil terminal is riveted to a separate brass strip, which is countersunk in the hard-rubber head of the

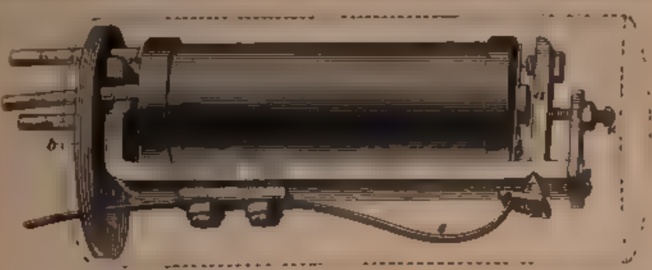


FIG. 13

coil and held in place by a screw *x*. The armature *a* works on a knife edge *c*, where it is held in place by the spring *g*, which, in turn, is supported by the core and held against the end piece by a hexagonal nut on the core *m*. The length of the air gap between the armature and frame may be varied by tightening or loosening the screw *f*. A freezing spring *h*, between the iron end-piece *n* and the armature *a*, is held in place by the screw *f*, which is adjusted to prevent the sticking, or *freezing* as it is termed, of the armature to the end-piece *n*. This relay may be mounted with either side up as

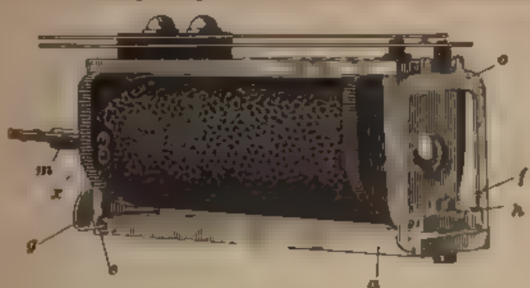


FIG. 14

occasion demands. The shell is made of seamless drawn aluminum. It is lighter and it is claimed that it does not corrode or become defaced as readily as a steel shell. When the relay is energized, the armature is drawn toward *n*, thereby raising the piece *o*, which moves the contact springs.

DIRECT-CURRENT RELAYS

21. A **non-inductive relay** may be made by covering the core with a copper tube, which need not be insulated from the core. Several methods are used so that a relay will be operated by a direct current, but not by an alternating current. The most common method consists in covering the iron core of the relay with a copper tube. When an alternating current flows through the winding of such a relay, a current is induced in the copper shell, which neutralizes more or less the effect of the original current on the iron core, which may, therefore, not be magnetized sufficiently to attract its armature. The copper covering, therefore, seems to act as a shield or damper and prevents the magnetization of the iron core, whereas the steady current from a battery readily magnetizes it. The iron core, not being magnetized appreciably by a high-frequency current, causes no appreciable impeding effect on voice currents. With direct current, there will be only a momentary current in the copper shell when the current starts and stops; this will not prevent the relay from working. Such a relay acts slowly, both in pulling up and releasing its armature. This is not usually a disadvantage, and in some cases is very useful. The relays used in series with the line in some Strowger automatic telephone systems are so designed.

If the frequency of the alternating current is high enough, a non-inductive resistance relatively high compared to that of the relay winding may be connected in parallel with the relay coil. Enough of the direct current will pass through the relay winding on account of its lower resistance, to operate the relay; whereas most of the alternating current will pass through the higher non-inductive resistance because of its lower impedance. The supervisory relays in some Bell central-energy systems are wound in this manner, the non-inductive resistance being wound double over the relay coil.

22. The relays shown in Figs. 15, 16, and 17 may be operated by direct, but not by alternating, current, according

to W. W. Dean, who described them in the American Telephone Journal. The core of the relay shown in Fig. 15, which is said to be very effective, has two windings *a*, *b*, and near one end of the armature is a small holding magnet provided with a winding *d*. When an alternating current is sent through the winding *a*, a current will be induced in the winding *b*, which will flow through the winding *d* of the holding magnet, thereby energizing it and preventing the armature of the relay from being drawn forwards. The direct current will attract the armature because it will not cause a current to flow through the holding coil *d*, and thereby hold the armature.

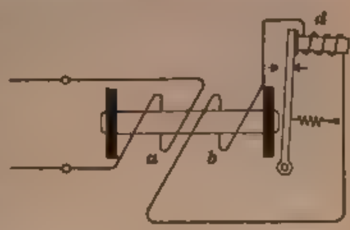


FIG. 15

Another very simple arrangement is shown in Fig. 16. In this case, a repeating coil or transformer is used to generate the current through the holding-coil circuit. Although this method is more expensive, it is much more effective.

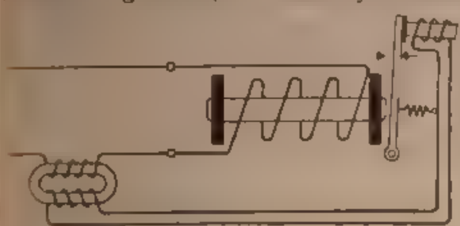


FIG. 16

Still another arrangement is shown in Fig. 17. An alternating current can flow through the winding *a* and also through the condenser *c* and the winding *d*, thereby energizing the holding coil *d*, which prevents the relay from attracting its armature. A direct current, however, can flow only through the winding *a* and will, therefore, cause the armature to be attracted.

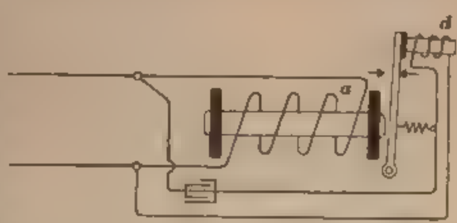


FIG. 17

ALTERNATING-CURRENT RELAYS

23. Relay for Low Frequencies.—If an ordinary relay has an alternating current of low frequency, about sixteen cycles per second, passed through its magnetizing coils, the armature usually vibrates and fails to maintain a closed local circuit. This difficulty has been overcome by means of flexible spring contacts and heavy armatures, but such relays are sluggish in their action and uncertain in releasing their local contacts when adjusted to operate with a small amount of energy. For these reasons, Frank F. Fowle explains in the Electrical World and Engineer for November 19, 1904, how he designed a relay that has proved more satisfactory. He provides a second magnetic circuit, energized by a separate winding that will exert a force of attraction on the common armature while the force of attraction due to the ordinary winding is zero. A condenser is employed to so displace the phase of the current in one of the two windings that the two independent forces, exerted on the common armature, do not pulsate in unison, but in such a manner that one is a maximum at the moment the other is zero. A relay with the two windings on one and the same core will not fulfil these conditions; separate cores must be provided.

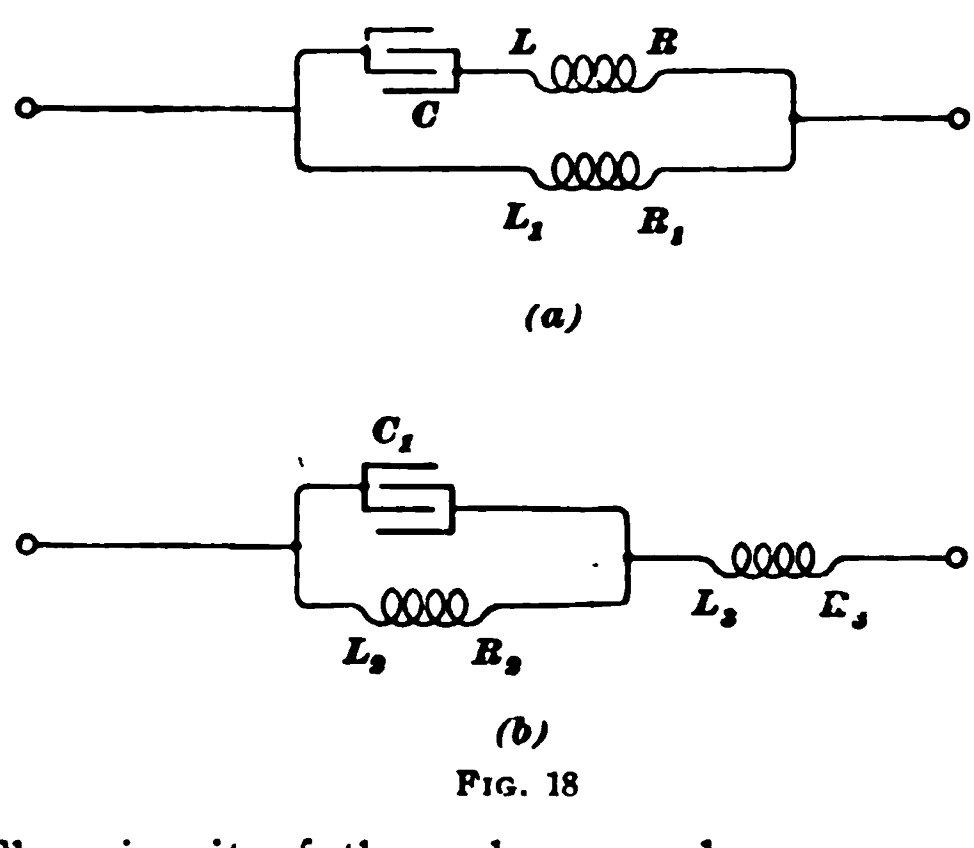


FIG. 18

24. The circuit of the relay may be arranged as shown at (*a*) or at (*b*) in Fig. 18, in which R, R_1, R_2, R_3 represent

the resistances and L, L_1, L_2, L_3 the inductances of the two coils on the relay, and C, C_1 the capacities of the condensers.

In order for the current with the arrangement shown at (*a*) to be a maximum in the relay coil R when it is a minimum in the other relay coil R_1, the following relation between the various quantities must be satisfied:

$$\frac{2\pi n L_1}{R_1} = -\frac{R}{2\pi n L - \frac{1}{2\pi n C}} \qquad (1)$$

in which n = number of cycles per second. If the windings LR and $L_1 R_1$ in (*a*) are to be similar, that is, if $R = R_1$ and $L = L_1$, in order for the current in R to be a maximum when that in R_1 is a minimum, and also to have equal currents in the two windings, we must have

$$R = R_1 = 2\pi n L = 2\pi n L_1 = \frac{1}{4\pi n C} \qquad (2)$$

From equation (2) we get the capacity C, in microfarads, required in the condenser to be

$$C = \frac{10^6}{8\pi^2 n^2 L}$$

in which L = the inductance of each winding, in henrys.

25. In order for the current with the arrangement shown in (*b*) to be a maximum in the relay coil R_3 when that in R_2 is a minimum, we must have

$$2\pi n L_2 = \frac{1}{2\pi n C_1} \qquad (1)$$

If the windings in the arrangement shown in (*b*) are to be similar, that is, if $R_2 = R_3$ and $L_2 = L_3$, the conditions for equal currents in both windings—the current in one to be a maximum when the current in the other is a minimum—are

$$R_2 = 2\pi n L_2 = \frac{1}{2\pi n C_1} = R_3 = 2\pi n L_3 \qquad (2)$$

The relation between the inductances, in henrys, of the two windings and the required capacity C_1 in microfarads, of the condenser is

$$C_1 = \frac{10^6}{4\pi^2 n^2 L_2} = \frac{10^6}{4\pi^2 n^2 L_3}$$

It is beyond the scope of this Course to give the mathematical theory of alternating currents on which the derivation of these formulas and equations depends.

26. The two types of relays designed for an alternating current of 16.7 cycles per second are shown in Figs. 19 and 20. The design in Fig. 19 is the cheaper and the most readily adjusted and repaired; that in Fig. 20, of the iron-clad tubular form, is preferable for telephone work because it may be readily sheathed with copper to reduce cross-talk between adjacent relays and is adaptable to mounting in rows on a single supporting strip. In testing the efficiency of these arrangements, a 12-volt lamp was arranged in series with a battery and the local contacts of the relay; the absence of flickering of the lamp was taken to indicate that the local contacts maintained a constantly closed circuit.

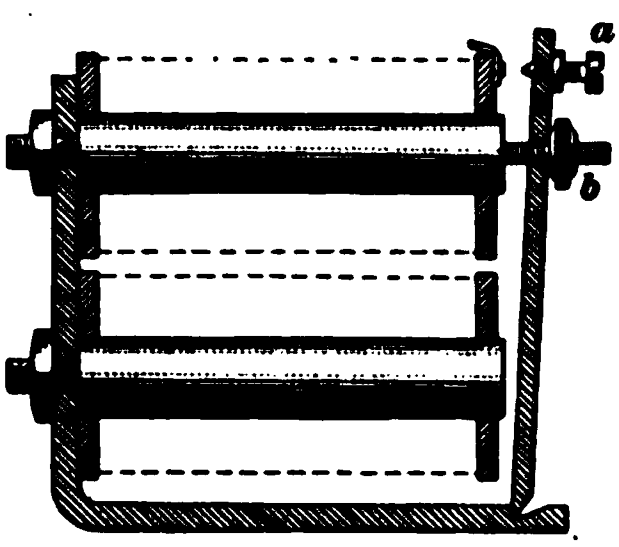


FIG. 19

27. The relay in Fig. 19 consists of two parallel electromagnets, attached to a common yoke. There is one adjustment *a*, governing the air gap when the relay is energized, and another *b*, governing the air gap when the relay is normally deenergized; these adjustments control the maximum releasing current and the minimum operating current, respectively. A relay having cores 2 inches long and coils 1 inch in diameter was wound with 10,500 turns of No. 37 B. & S. gauge, single, silk-covered wire on each spool, the resistance being 900 ohms per coil. It could be adjusted to operate satisfactorily on 3 milliamperes with the circuit of Fig. 18 (*a*), using a condenser of 2 microfarads, and on 2 milliamperes with the circuit of Fig. 18 (*b*), using a condenser of 4 microfarads. It operated satisfactorily on these sensitive adjustments when the current was increased between five and ten times the above values.

28. The relay shown in Fig. 20 consists of an iron-clad electromagnet having a second winding over an iron encasing sheath; a second and outer iron sheath makes the second winding iron clad also, and a disk armature is arranged within a brass cap on the pole end of the magnets. This relay has two adjustments similar to the former one and has the advantage of being dust-proof. A relay whose outer shell was 3 inches long and 1⅝ inches in diameter was wound with approximately 10,000 turns in each winding; the inner winding had an approximate resistance of 1,000 ohms and the outer 2,000 ohms. Tests on this relay, connected as in Fig. 18 (*a*) or (*b*), and using a condenser having a capacity between 1 and 3 microfarads, showed it to be nearly as sensitive as the other relay, when operating on 3 milliamperes.

FIG. 20

29. The iron-clad relay is preferable for use on telephone talking circuits, because its great impedance allows it to be bridged across the circuit and because a copper cylinder over the outer shell will prevent cross-talk with adjacent relays, due to stray magnetic fields. The variable stray magnetic fields tend to produce, in the low-resistance copper sheath, induced currents that set up an opposing field, thereby practically annuling any effect that the stray fields would otherwise have had on the interior parts of the relay. The relay shown in Fig. 19 is preferable for purely telegraphic or signal circuits or for alternating-current track circuits in automatic-block railway signaling systems.

30. Dean Slow-Acting Relay. The slow-acting relay devised by Mr. Dean for the Western Electric Company is shown in Fig. 21. Although the relay is sluggish it is said to act strongly and certainly even under the influence of low-frequency alternating or pulsating ringing currents.

The magnetic circuit of the relay consists of the core fastened at the rear to a piece of iron *c* that projects in front a considerable distance beyond the core on each side and the armature *d*, which is pivoted, between the two side pieces *c*, *c*, on trunnions *e*. The heavy soft-iron block forming the armature *d* is so balanced that it normally rests against the stop *f*, as shown in the figure. When the magnet is energized, the armature *d* moves into a horizontal position, causing the screw *g* to make a rubbing contact with spring *n*, thus closing the circuit to be controlled. The stop *o* has a copper pin that limits the motion and also prevents actual contact between the iron armature *d* and the core, and hence prevents the sticking that might otherwise occur. The armature *d* is pivoted almost at its center of gravity, which permits the use of a very heavy and therefore sluggish armature, and yet the relay may be quite sensitive and efficient. Such a relay, when wound to a resistance of 1,000 ohms with 14,500 turns of No. 36 B. & S. copper wire, is said to be operated by 75 volts, alternating, through 17,000 ohms and a 2-microfarad condenser in series with it.

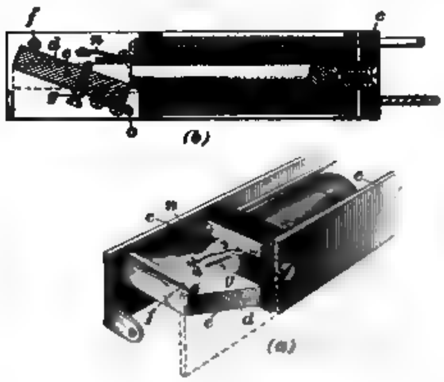


Fig. 21

31. To Prevent Chattering of Relays.—With certain central-energy systems, wherein a relay is required to maintain the continuity of a subscriber's line during connection between his station and the line jacks, trouble has been experienced when an attempt has been made to signal by pulsating currents in party-line work, because of the chattering of the controlling relay during the application of the pulsating current.

Mr. David F. Stokes considers that this chattering is due to the discharge of the subscriber's station condenser in the interval between impulses of current, this discharge taking place to earth through the controlling relay, and, being of an opposite sign from the normal current, it releases the armature. He claims to have found a remedy for this effect in the shunting of the relay by a high-resistance, non-inductive shunt, which, while not affecting the normal operation of the relay, carries the condenser kick around it.

32. Relay Winding.—The wire with which a line relay is wound must be sufficiently large and high in resistance to stand for about 10 minutes, when a line is short-circuited, sufficient current to open the protecting fuse or heat coil on the line. The latter, in central-energy exchanges, is usually supposed to carry $\frac{1}{4}$ ampere indefinitely. If not of sufficient size, the coil will be damaged by heat before the line fuse or heat coil opens the circuit. The winding space on a line-relay spool should be at least $2\frac{1}{2}$ inches long, diameter of core $\frac{3}{8}$ inch, outside diameter of spool heads 1 inch. The winding should only come to within $\frac{1}{16}$ inch of the outside diameter of the spool heads, making its outside diameter $\frac{7}{8}$ inch. Such a coil wound to 250 or 300 ohms will give a positive action over the longest line practicable for a central-energy system. Systems requiring lower-wound line relays must have larger spools to permit of a sufficient number of turns. A good test for a line relay is to operate positively through 750 ohms external resistance with the voltage of the battery necessary for operating the system; this will be equivalent to a very long exchange line. For positive operation, a margin of 25 per cent. under the limit is allowed.

Where desirable, there should be no difficulty in operating a 100-ohm line relay through 2,500 ohms with a good safe adjustment, and a 500-ohm relay through 4,000 or even 5,000 ohms on 22-volt circuits.

RESISTANCE OF RELAYS

33. Since the line relay must usually operate in series with lines of various lengths, it should have enough turns to operate properly on the longest, or highest-resistance, line circuit. Moreover, even the shortest line circuit may have considerable resistance. One designer found that a relay wound to 60 ohms was satisfactory.

The cut-off relay, however, is usually connected in a circuit that does not go outside the exchange, and this circuit has very little resistance in addition to that of the relay. Hence, a larger and very nearly constant strength of current can always be depended on, for which reason fewer turns of a larger wire can be used, giving a lower-resistance relay than the line relay.

The line-pilot and night-bell relays must be of much lower resistance for several reasons. One is that it is very desirable to use lamps that may be operated and will not be injured by the full voltage of the main battery; hence, the drop through a pilot relay must not be large enough to appreciably affect the light given by a lamp with which it is connected in series, or injure the lamp if the relay is cut out of the lamp circuit.

34. Pilot Relays.—While pilot relays may be of the same general construction as other relays, it is usually necessary to make them larger in order to contain the larger coil usually required. A pilot relay must have enough ampere-turns to operate with the smallest current that passes through it; for instance, a line-pilot relay must close when the current from one line lamp only passes through it. They must, however, be wound with large enough wire to not overheat when all the circuits for which it forms a common return are closed, or at least from as many circuits as are apt to be closed at any one time. Moreover, they must usually be of such low resistance as not to cause enough drop of potential through the coil to prevent the using and proper operation of lamps made for the full voltage of the battery when the

greatest current and, therefore, the greatest drop occur through the pilot relay.

Furthermore, if the pilot relay is cut out of the circuit so that the lamp receives the full voltage of the battery, the increase in voltage must not be great enough to injure or shorten the life of the lamp. For the reasons just given, a line-pilot relay must have a large number of turns of relatively very large wire, which requires a coil usually larger than is necessary for other purposes.

35. The relays should be so constructed and mounted that they may be readily removed or inspected, the contact points being arranged so as to be easily seen without disturbing the mechanism. The relay should have a good iron circuit and, including the contact springs, should be enclosed in an iron or sufficiently heavy brass, copper, or aluminum case to prevent cross-talk with adjacent relays in other circuits, and as much as possible excluding the entrance of moisture and dust from the working parts.

36. Proper Winding of Coils.—All the coils should be wound to stand the entire voltage of the battery without danger of burning out. Coils used in switchboard apparatus are sometimes wound with such fine wire that they burn out before the exchange protecting devices have had time to operate. Such apparatus should be avoided.

Where a system is balanced, the coils used as impedances on each side of the battery—that is, those through which current is furnished to the line—should have exactly the same number of turns of the same-sized wire wound on cores of the same size. This, of course, will produce a perfectly balanced circuit, but it is not absolutely necessary in every case; and if the coils are within 10 per cent. of each other there will be no noticeable unbalancing except on a connection with extremely long toll lines. As the connection is almost always made through a repeating coil in these cases, there will be no bad effect.

SIGNAL LAMPS

37. Line Lamps.—On central-energy switchboards, the local subscribers' line signals are usually $\frac{1}{3}$-candlepower incandescent lamps mounted in opaque tubes provided with small opalescent glass jewels, set in shouldered caps, to allow them to be readily inserted or removed from their sockets from the front of the switchboard. In Fig. 22 is shown a lamp *a* with the base *b* and metal contact pieces *c*, *d*

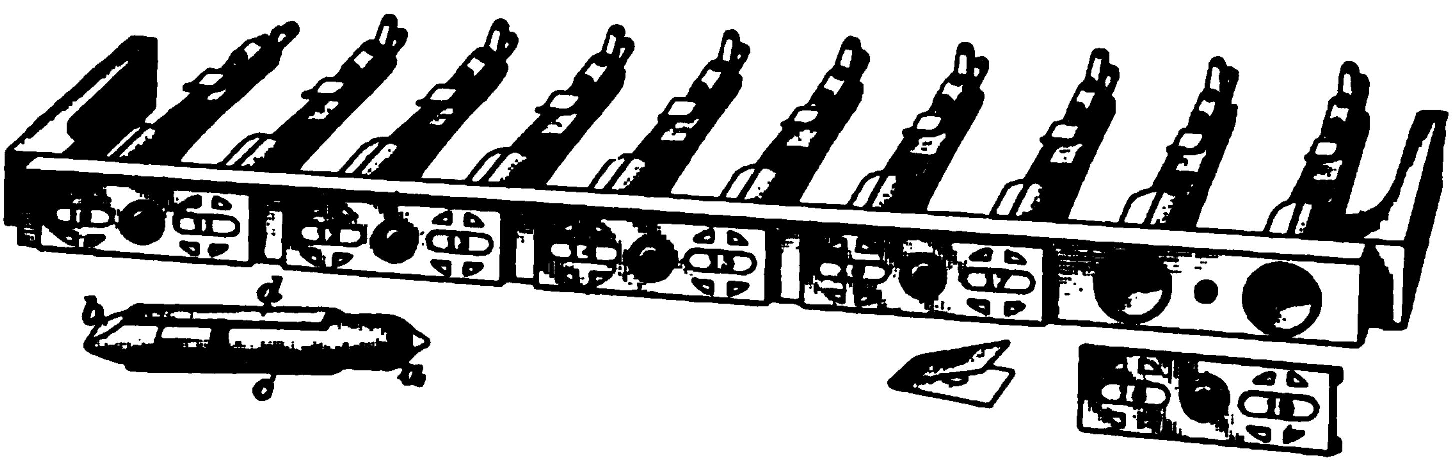


FIG. 22

that form the terminals of the carbon filament inside the exhausted glass tube *a*, which is about $\frac{5}{16}$ inch in diameter. The base *b* to which the glass tube and contact pieces are rigidly secured is made of dry hardwood. The lamp jacks are provided with two insulated springs; one makes contact with *c* and the other with *d* when the lamp is pushed into the jack. The pointed tip shows where the lamp was sealed after being exhausted of air. The lamp *l*, shown in Fig. 25, is sealed at the lower end, which is embedded in the insulating material that forms the base of the lamp. In some lamps, the base is made of an insulating cement.

38. Supervisory signals usually consist of $\frac{1}{3}$-candlepower lamps, mounted in an opaque tube similar to the line signal and provided with an opalescent jewel, and protected by an arched open-work metal guard to prevent the breaking of the opal from impact of the plugs and also provided with means for conveniently removing the lamps from the top of the keyboard without the use of special tools.

Each equipped operator's position is very often provided with three pilot signals, one to give a signal in connection

with the subscriber's line signal, one to give a signal in connection with the supervisory signal, and one for use in the ringing circuit. The pilot signals are usually $\frac{1}{3}$-candlepower lamps mounted in an opaque tube, provided with a large brass cup receptacle in which is mounted the colored bull's-eye prism. The pilot-lamp sockets are so constructed that the lamps may be readily removed from the front of the board, the same as the line or supervisory lamps.

39. **The life of switchboard lamps** used as signals is not so much a question of use as it is a question of mechanical injury. Experience seems to show that the average life of a lamp is from 5 to 10 years for line signals and over 1 year for lamps mounted in the key shelf and usually associated with the cord circuit. The shorter life of the latter lamps is due to the breaking of the filament, which is caused by the impact of the plugs on their seats. In 1905, lamps cost about 20 cents each in small quantities and less in large quantities.

40. The Kellogg Switchboard and Supply Company make tipless switchboard lamps of the approximate voltage and candlepower given in the accompanying table and requiring the current mentioned.

Voltage	Candlepower	Ampere
3	.2	.2
4	.2	.2
4	.2	.4
5	.2	.15
6	.2	.15
10	.2	.1
12	.2	.1
14	.2	.1
16	.2	.1
20	.3	.1
24	.3	.075
30	.3	.085
40	.5	.085
48	.6	.075

These lamps are tipless, that is, rounded off on the front end, which, it is claimed, forms a small but effective convex lens that focuses the light rays in the most desirable direction. The top of the lamp having no tip offers at least a freer passage for the light and is less liable to be broken. Platinum is used to carry the circuit through the glass.

LAMP JACKS

41. A **lamp jack** is a device for holding and making contact with a lamp used for signaling purposes, such as a line or supervisory lamp. Lamp jacks are usually arranged in banks of ten, and are so constructed that they may be readily installed or removed from the back of the board. Alternating with the strips of line-lamp jacks and corresponding in number are mounted the necessary answering jacks, which are also arranged in banks of ten, mounted on from $\frac{6}{10}$- to 1-inch centers, the construction of the banks being the same as for the multiple jacks, which are, however, arranged in banks of twenty, mounted on from $\frac{3}{10}$- to $\frac{1}{2}$-inch centers.

42. The Dean Electric Company constructs its lamp jacks entirely from metal, with hard-rubber insulation for the contact springs, as shown in Figs. 22, 23, and 24. The line-lamp jacks are mounted on a rigid metal strip, and provided with protecting covers and removable number plates, as shown in Fig. 22.

The line-lamp cover is made in the form of a guard from tempered spring steel, so as to prevent breakage of the translucent covers, also breakage of the lamps by operators carelessly pushing the tip of the answering plug through them. This is a big item where no protection is used. In some cases, as many as one-half of the line-lamp caps have been broken in a few months. These caps are removable, being held in place by spring pins that pass through holes in the lamp-jack mounting. The numbers that are furnished in these caps are removable and interchangeable.

The use of a metal-frame lamp jack serves to radiate the heat from the lamp very quickly; furthermore, the metal will not become soft and warp as in the rubber lamp-jack strip. Forty-volt systems require this new construction, due to the greater dissipation of energy, the lamps requiring nearly twice the watts as for the 24-volt system.

43. Fig. 23 shows a supervisory jack of tubular form, the tube extending through the key shelf so as to be flush

with the top surface. This provides a metal-bushed hole for retaining the lamp cap *c*. This lamp cap is made with a heavy German-silver removable guard *b* that threads over the opal *d* on *c* so as to serve as a protection for the opal. The pilot lamp jack and cap shown in Fig. 24 are made similar to the supervisory lamp jack and cap, except that the cap and neck of the jack-tube are larger and that no guard is provided for the cap. The same size of lamp is used in all these jacks, the pilot jack utilizing more of the light so as to give a larger signal.

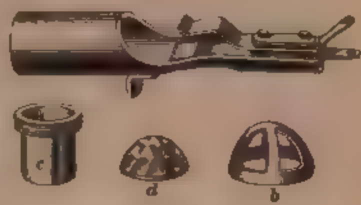


FIG. 23

FIG. 24

44. Kellogg Lamp Jacks.—In Fig. 25 (*a*) is shown a single supervisory lamp jack; and at *b*, a strip of five transfer, or trunk, lamp jacks with one taken apart, as made by the Kellogg Switchboard and Supply Company. The lamp *l* has for terminals two strips of brass cemented to the glass and extending backwards, the two strips being insulated from each other by a small block of wood. When the lamp is slipped into the lamp jack, these two strips engage with the jack-springs. The lamps may be inserted and removed from the front of the switchboard by the aid of the lamp extractor *i*.

Each lamp is protected by a lamp cap *g*, which also serves as a sort of number plate. The cap may be readily removed by the use of the lamp-cap extractor *d*. The lamp cap, as shown at (*c*), consists of a shoulder *e* that is screwed over the tubular portion *f*, and three disks held in place between *e* and *f*. The mica disk *o* is nearest the lamp; on it is placed the paper disk *n* bearing the number while the glass disk *m* covers and protects the mica and paper disks. When

the lamp is burning, the number on the paper disk shows up clearly. Ordinarily, the operator is not concerned with the number of the line she is answering; she simply sees the signal and plugs into the jack immediately above it. But at times, such as when a lineman is testing, it is convenient for her to be able to know at a glance the number of the line on which a call comes in. Should an operator carelessly punch

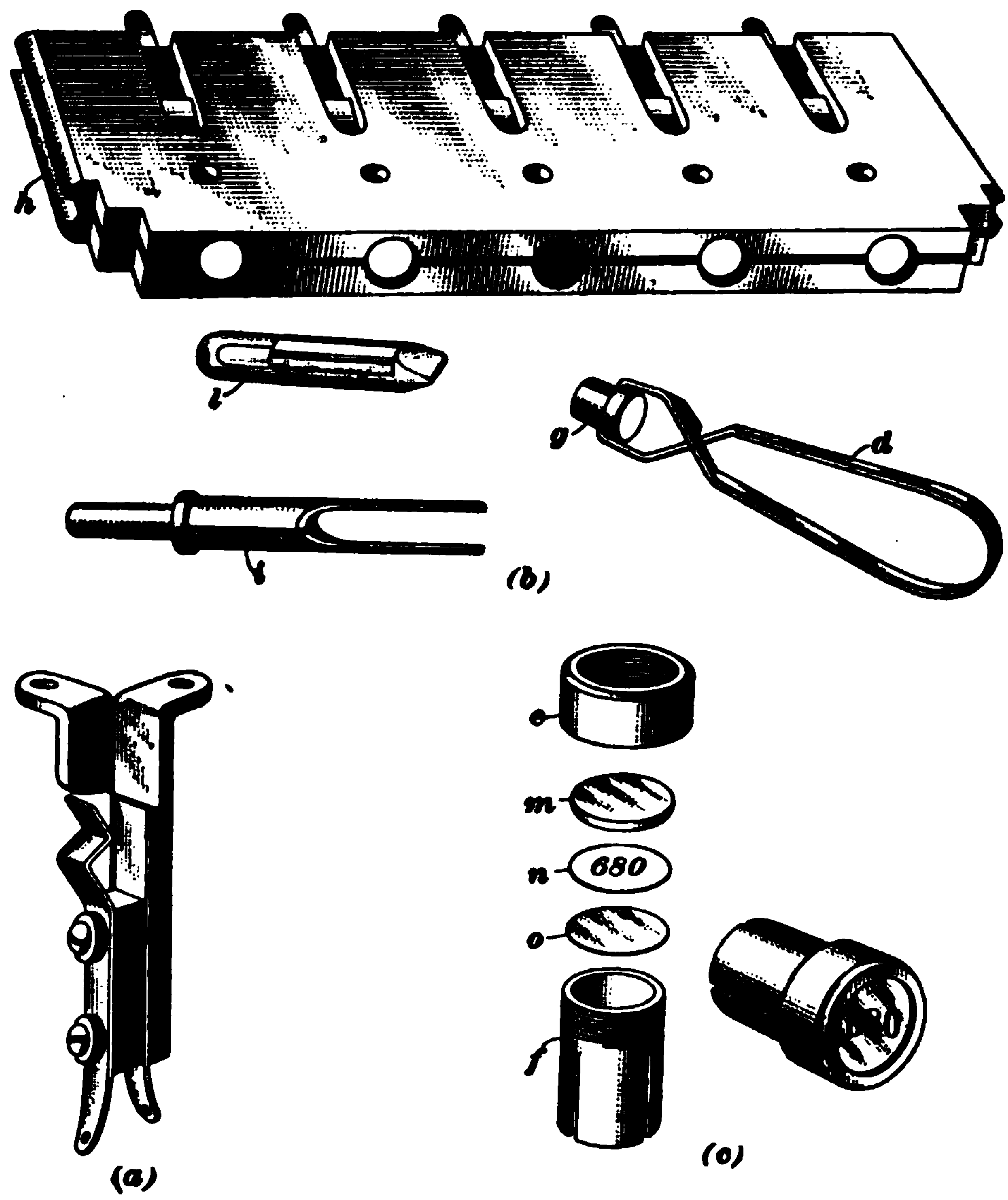


FIG. 25

a plug through the disks, it may readily be repaired by unscrewing the shoulder and inserting new disks.

45. The arrangements of the ringing and listening keys, lamp signals, lamp jacks, and spring jacks should leave all working parts readily accessible for inspecting and testing from the front of the board. The operators' receivers

should be provided with a cord and plug so they may be attached and detached at a cut-in jack in each position, mounted underneath the key shelf.

AUXILIARY EXCHANGE DEVICES

46. In large exchanges especially, many special devices are used to facilitate and render less laborious the work required of the operators. A few such devices will be explained here and others in connection with the systems with which they are used.

BUSY- AND TONE-TEST SIGNALS

47. Use of Phonographs.—In one large transfer switchboard system, phonographs were used to do a large part of the talking that the operators usually do. Two phonographs were used, one of which constantly repeated the sentence, "Busy, please call again," while the other repeated the sentence, "Subscriber called for does not reply." Each of these instruments repeated into a transmitter connected in a local circuit with an induction coil in the ordinary way. The terminals of the secondary coils of the "busy" and "does not reply" phonographs were connected with spring jacks on the various sections of the board. When an operator found that a line called for was busy, she merely inserted the plug that would be used to complete the connection into the phonograph jack, and the phonograph repeated its sentence to the subscriber. In a similar manner, an operator could inform the calling subscriber that the called-for subscriber did not respond.

The use of these phonographs not only saved the time of the operators, but frequently prevented the anger of a disappointed subscriber from grating on her nerves; and this is an important consideration, especially in very busy times of day, when the nerves of the operator are necessarily heavily taxed.

48. Tone tests may be obtained by interrupting a current a sufficient number of times per minute to produce a

musical sound if it passes through a telephone receiver. Currents of this kind are used for various purposes, such as notifying the subscriber that the line he is calling for is busy, or an operator that the line she has a call for is out of order or connected to a toll, or long-distance, line. These currents for producing different tones are made available for every operator at a switchboard, by having jacks that are connected to the source of this current, multiplied at each position, as shown in Fig. 26.

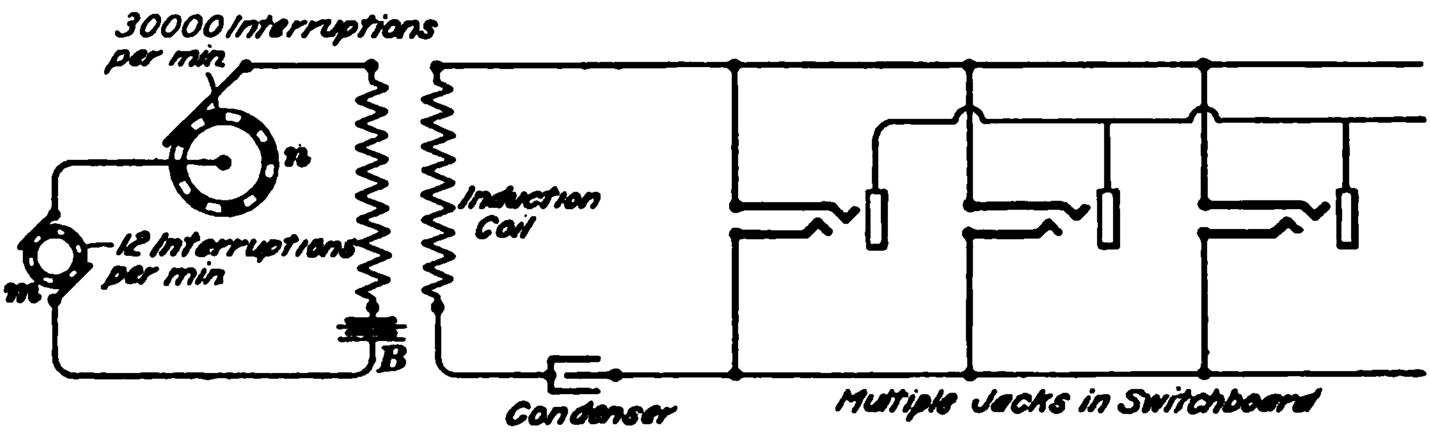


FIG. 26

A **busy back** is an arrangement for automatically notifying a subscriber, by some form of signal, that the party desired is engaged in conversation. The use of busy phonographs for this purpose has already been explained. In modern exchanges, tone tests are used for busy-back and other signals. The operator sends a busy-back signal by inserting the calling, or as it is frequently termed, the connecting, plug in a busy-back jack.

49. Tone Test for Other Purposes.—If an operator wishes to put a tone test on a line in order to reserve it for a long-distance connection, she inserts a plug in the jack connected with the tone-test circuit. The other plug of the pair she inserts in the multiple jack of the line to which she wishes to apply the tone test. Any other operator testing this line will hear the musical tone, which informs her that the line is being held for a toll connection.

The interrupted current is usually obtained either by a revolving break wheel, or some form of commutator, usually attached to the ringing generator, or by a buzzer and battery. Sometimes, the interrupted circuit is further interrupted so

as to give a break in the musical tone, making the signal more distinct, or to give another signal having a different meaning. In Figs. 26 and 27 are shown arrangements that may be used for this purpose. Current from *B*,

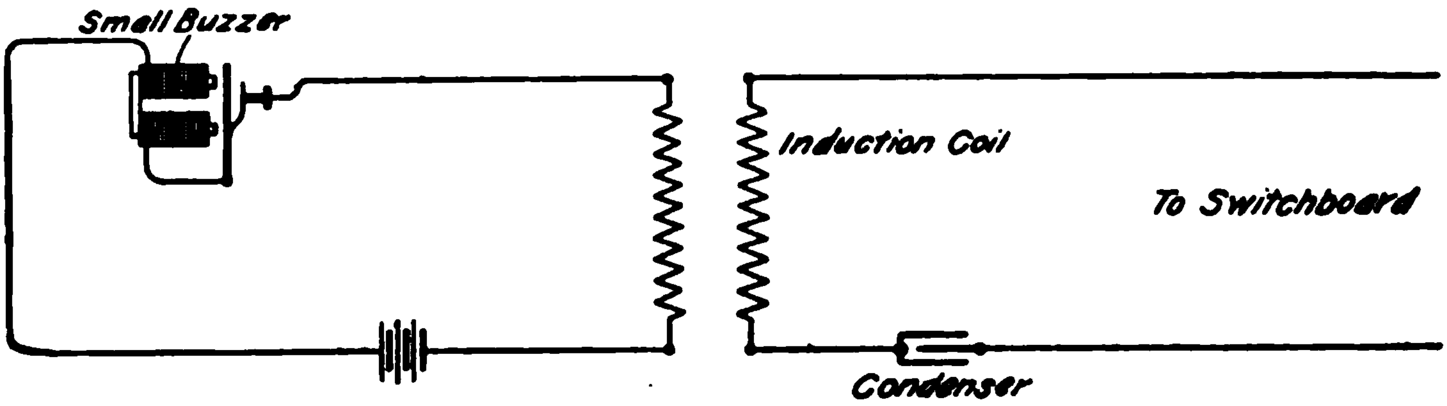


FIG. 27

Fig. 26, after being interrupted by commutator *m* may be used for one test; while the same current, after passing through commutator *n* may be used for some other test.

A line that is out of order should have the thimble of its jacks connected to a source giving a shrill humming sound until the line is clear. An operator testing such a line knows the meaning of the sound and so informs the calling subscriber.

POSITION SWITCHING KEYS

50. It is very often desirable, during the night, or such other times as but few calls are being received, to be able to connect the listening and ringing keys at two or more

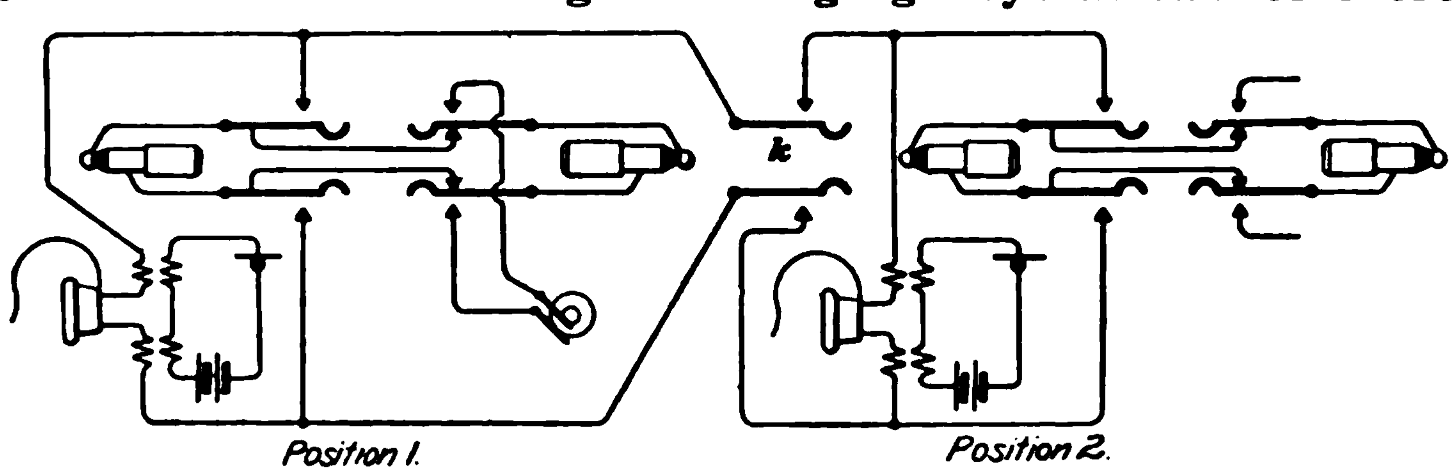


FIG. 28

positions together, so that an operator at one position may be able to attend to two or more positions. To assist in doing this, her receiver cord may be long enough to allow her to walk in front of the necessary positions; or, better still, she may be provided with a breastplate transmitter and

receiver set with a twin plug that she can insert in a jack in the front of the key shelf at any position. The keys used for connecting together two or more operators' listening sets are called **position switching keys**, and one arrangement of such a key is shown in Fig. 28. By closing the key *k*, the listening circuits at the two operators' positions are connected together, thus enabling one operator to attend to two positions. A similar circuit and key between position *2* and a third position will enable one operator to attend to three positions, etc. This arrangement has the objection that two or more operators' listening sets are connected in parallel when listening across a circuit.

51. Another arrangement whereby all the listening keys at two positions may be connected to the operator's set at either position is shown in Fig. 29. Wires *a*, *b* run to the operator's set at position *1*; *d*, *c* to operator's set at position *2*;

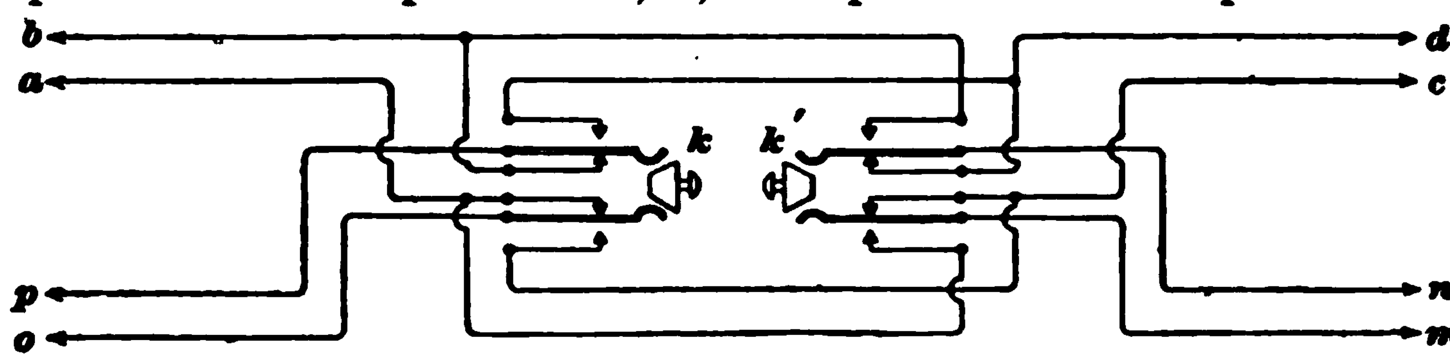


Fig. 29

p, *o* to all listening-key contacts at position *1*; and *n*, *m* to all listening-key contacts at position *2*. Each operator's set is not connected as usual directly to the listening-key contacts at its own position, but only to one of the keys *k*, *k'*, as shown in this figure. With both keys *k*, *k'* in their normal or unused positions, the listening keys at position *1* are connected to the operator's set at position *1*, and the listening keys at position *2* are connected to the operator's set at position *2* as usual. With the key *k'* closed, all the listening keys at positions *1* and *2* are connected to the operator's set at position *1*, and the operator's set at position *2* is disconnected. Similarly, with the key *k* closed, all the listening ing keys at positions *1* and *2* are connected to the operator's set at position *2*, and the operator's set at position *1* is disconnected. With both keys closed, the listening keys at

position *1* are connected to the operator's set at position *2*, and the listening keys at position *2* are connected to the operator's set at position *1*. There would be no object in closing both the keys in this manner. The switching key may consist of two separate keys or of one combined key, the handle of which may be used to close either side of the key.

The same switch and connections may be used to connect the ringing keys at two or more sections together, when the operator must use a hand generator located at her own position. When applied to ringing circuits, the wires *p*, *o* should be connected to the ringing keys at position *1*, and the wires *n*, *m* to the ringing keys at position *2*, while the wires *a*, *b* should be connected at position *1* to the hand generator, and *d*, *c* to the hand generator at position *2*. When a power generator or pole changer is used at all times, there is no need to connect ringing keys in this manner.

SWITCHBOARD SYMBOLS

52. Construction of Indicating Plugs.—The use of plugs inserted in line jacks to indicate to the operators irregular conditions of lines has been adopted by practically all exchanges. By their use, the operator's attention can be

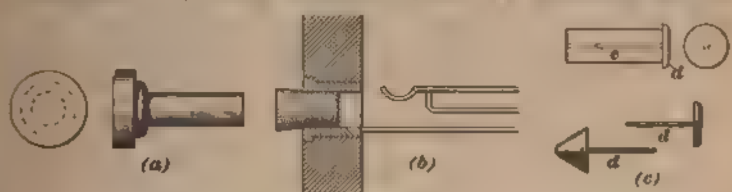


FIG. 30

called to telephones discontinued, out of order, etc., when she starts to make a connection with such a line. It also saves the placing of lists of lines in such conditions on the face of the board.

Fig. 30 (*a*) shows the ordinary plug used for the purpose. This plug is made of wood fiber or pressed paper and can be obtained in different colors or marked in any suitable manner

to indicate different conditions of the line in whose jacks it is placed.

Small exchanges, as well as large ones, can use these plugs to good advantage, although two or three styles may be all that are required. Where only a small number of such plugs are required, a cork, colored suitably, may be used; but corks have the serious objection of chipping off and finally getting pushed into the jack. Corks, which may be obtained at drug stores, should be larger than the jack and placed as shown in Fig. 30 (*b*). A cheap and substantial substitute, as shown in Fig. 30 (*c*), may be made of common gilt upholstery nails *d*, *d* and a cylinder of wood *e* the size of the jack, and about $\frac{5}{8}$ inch in length. The wood can be obtained in pieces several feet long from any cabinetmaker, who uses them for dowel-pins, and can be easily cut in sections of the required length with a knife. It may be necessary to drill a hole for the nail to avoid splitting. The round-headed upholstery tacks may be used for telephones discontinued, and the pointed ones for lines that are out of order. They are put in place by the chief operator at the wire-chief's orders. When a line is all right, the plug is of course removed. Other uses of these plugs will occur to any manager and will make operating easier.

STANDARD USE OF INDICATING PLUGS

53. In 1905, the National-Interstate Telephone Association adopted a standard set of rules for use in the operation of telephone exchanges.* Since these rules are quite long, only those relating to switchboard symbols will be given here.

These symbols are so well shown in Figs. 31, 32, and 33 as to require very little explanation. The pay-station toll device, number 3, Fig. 32, is made by merely putting a protecting glass opal, such as used in exchanges having small lamps as signals, over the ordinary lamp used as a line signal.

*These rules were published in full in Telephony of Chicago for August, 1905, and other telephone journals of about the same date.

In small exchanges, where an "out-of-order" tone test is not in use, a white plug should be used, as indicated at *1*, Fig. 31; this would be an indication to the operator that the line is out of order. Also, where the exchange is not large enough to warrant a separate desk outfit for a monitor operator, a list should be posted on the board; and where instructions direct the operator to refer a call to the monitor, the operator should refer to her list for the information desired.

54. A yellow mark enclosing two or more multiple jacks, as shown at number *1*, Fig. 33, indicates that if the first line is busy, don't answer, or out of order, the second, third, etc. should be tried in the order named. A red mark enclosing a number of lines, number *2*, Fig. 33, should be handled the same as those enclosed in yellow lines, except that the lines enclosed in red are private branch-exchange trunk lines and, as usually constructed, must not be rung when the connection is first made. If, however, at the end of 30 seconds, the private branch-exchange call has not been answered, the operator should say, "I'll call them again," and will then ring in the usual manner.

A yellow mark over an individual-line multiple jack, as at *3*, indicates that this subscriber is being called by mistake, or otherwise annoyed, and all calls will be referred to the monitor or list, as the case may be, to determine the correctness of the call before the same is made.

A red mark over an individual-line multiple jack, as at *4*, indicates that the subscriber is having some trouble in getting his calls, and all "don't answers" on such lines should be immediately reported to the manager.

55. On party lines, where the number has been changed, telephone taken out, or the line is being watched for any other reason, calls for such numbers should be referred to the monitor or list, and will be designated as follows: A yellow mark representing a quarter circle on the upper left-hand corner of the multiple jack, number *5*, indicates the first party on the line, etc. In magneto-exchanges, the same symbol as is used on line opals will be painted on the

subscriber's drop, so that such symbols will be seen plainly when the drop falls.

56. Out-of-Order Cords.—In case one or both cords of a pair get out of order, a small rubber ring (a number of which should be placed at each operator's position) should be placed around the plug until such cord has been repaired.

PEG COUNT IN LARGE EXCHANGES

57. A record of the number of calls made per hour at each operator's position for one day is called a **peg count.** In large exchanges, where the operators handle flat-rate, message-rate, and pay-station calls, the calls in each class are usually recorded on tickets that differ in some respect for each class. In such exchanges, a method of making a peg count that has proved satisfactory is about as follows: When the peg count is to be made, these tickets are collected hourly, stamped with the date and hour in which the calls originated, and sorted out according to the three classes mentioned. The operators at incoming trunk positions should, preferably, be provided with registers operated by hand, one register being provided for each group of trunks. For each incoming call, the operator presses the register and its reading is recorded by a messenger or clerk at the end of each hour. The peg count furnishes information that shows the amount of business each operator is handling each hour of the day, and by comparing these results with the figures that experience shows to be correct, the efficiency of operation may be judged. For example, if the peg count shows that the average calling rate per line for flat-rate lines is 12 calls per day, then, on the basis that an operator can handle 1,800 flat-rate calls per day, it shows that each operator's position for handling lines of this character should be equipped with 150 lines; and as the standard central-energy board usually contains positions for three operators, this would require 450 lines per section of the switchboard. If the average calling rate per message-rate line is 4, and the operator's load is 800 calls per day, each operator can handle 200

1 Indicates that line is out of order.
2 Indicates that subscriber is disconnected for non-payment.
3 Indicates the number to which subscriber was changed.
4 Calls for lines thus plugged to be referred to monitor's desk.

FIG. 31

Red.
Yellow.

1 No toll subscriber; that is, this subscriber is not to be connected to long distance.
2 Pay-station subscriber.
3 Pay-station subscriber having toll device.
4 Pay-station subscriber having free service to doctors' telephones.
5 Measured-service subscriber.
6 Five-cent toll subscriber.

FIG. 32

Yellow line.
Red line.

1 Indicates two telephones for same subscriber.
2 Indicates two private branch-exchange lines for same subscriber.
3 Refer calls for this line to monitor's desk.
4 Maintain record of don't-answer calls on this line.
5 Refer *W* (or first party on line) calls to monitor's desk.
6 Refer *R* (or second party on line) calls to monitor's desk.
7 Refer *L* (or third party on line) calls to monitor's desk.
8 Refer *K* (or fourth party on line) calls to monitor's desk.
9 Refer *X* (or fifth party on line) calls to monitor's desk.
10 Refer *F* (or sixth party on line) calls to monitor's desk.
11 Refer *J* (or seventh party on line) calls to monitor's desk.
12 Refer *Y* (or eighth party on line) calls to monitor's desk

FIG. 33

such lines, and the equipment per section of the board should be 600 lines. If the average calling rate of the pay-station lines is 4, and the operator can handle 500 such calls per day, about 375 lines may be allowed per section.

58. By keeping an hourly peg count at the ring-down trunk positions, it is easy to determine when circuit trunks should be substituted for ring-down trunks; and also, by similar data taken on common trunk circuits, when it is advisable to change from common to ring-down trunks. The circuit trunk is probably the most efficient method for handling traffic where there are more than 75 calls each way per day between two exchanges. These various kinds of trunk circuits will be explained in connection with Bell trunk circuits. In distributing the load among the various subscriber operators, the manager must, of course, have some knowledge concerning the relative number of calls made per day by the various subscribers, so that the busy subscribers can be distributed at the intermediate rack among the various operators so as to equalize the work required of each operator.

59. Uniform answering with rapid and accurate service can only be accomplished by giving an operator enough calls to keep her busy and not more than she can handle properly, and by minimizing the work on each call. The service may be considered as good in large central-energy exchanges when the average answering is in 6 or 7 seconds, and when about 95 per cent. of all calls are answered within 10 seconds. This grade of service is obtained only under favorable conditions with the operator continuously under a competent supervising operator, who works under a chief operator. The practice in large exchanges is to have one supervisor for every eight or ten operators.

INDEX

NOTE.—All items in this index refer first to the section and then to the page of the section. Thus, "Construction and design of repeating coil, §11, p36," means that construction and design of repeating coil will be found on page 36 of section 11.

163 - 48